ELEMENTARY GENERAL SCIENCE

FIRST YEAR'S COURSE

J. B. JENKINS

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BELL'S NATURAL SCIENCE SERIES
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BY

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LONDON

G. BELL AND SONS, LTD.

1931

First published 1927
Reprinted 1928, 1929,
1930, 1931

Printed in Great Britain by
NEILL & CO., LTD., EDINBURGH.

PREFACE

The syllabus covered in this book is intended to provide an interesting and instructive course in general science. It is hoped that it will afford a comprehensive introduction to more advanced work in Physics and Chemistry.

The subject-matter is dealt with under three parts :

Part I.—Practical, where the pupil is given express directions as to the carrying out of the experiments, and is led by a series of questions to gain first-hand knowledge, and, what is more important, is trained to think and to reason *inductively* ;

Part II.—Theoretical, where the results of each experiment are discussed, and valuable scientific facts learned ;

Part III.—Applications, in which these facts are used to show the relation between the science-room and the outside world, and the pupil taught to apply the knowledge gained to explain *deductively* common everyday happenings.

Short historical paragraphs have been introduced, thus adding to the interest and at the same time showing the international aspect of the subject.

The book was at first undertaken at the express desire of a large number of teachers who found themselves called upon to teach elementary practical science in the new Advanced Divisions of Scottish schools. It provides sufficient work for a two years' course of about 4½ hours per week, or a three years' course where only 3 hours per week are available.

I wish to express my gratitude to my former colleague, Miss J. L. Florence, M.A., High School of Stirling, for reading through the manuscript and suggesting valuable alterations, and to my wife for assistance in reading the proofs.

J. B. J.

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CONTENTS

INSTRUCTIONS

Each experiment consists of two parts—Method and Questions.

Read through the Method, noting the apparatus required for the experiment you have to do ; and procure the apparatus.

Now follow carefully the instructions detailed in the Method.

The numbers in the Method refer to the Questions corresponding ; answer these Questions as you proceed with the experiment.

The Questions contain the most important lessons you have to learn from the experiments.

Besides, you will get into the habit of looking for the reason why certain things happen, and this is of more importance than simply trying to remember facts, though, of course, the very important facts you do learn in the course of your work must not be forgotten.

When you have performed the experiment read and discuss the matter in Part II (Theoretical) relating to the experiment.

Then enter your record in your notebook, according to the suggestions below.

Part III (Applications) contains mostly some interesting everyday happenings that may be explained by the principles you have learned in the other two parts.

Suggestions for Keeping Notebooks

1. Write on the right-hand pages, keeping the left-hand pages for diagrams, definitions, laws, etc.

2. Begin each experiment on a new page, and write neatly.

3. In the centre of the first line write the number of the experiment, and at the end of the same line, the date, *e.g.*

. . . . . *Experiment* 26 . . . 7.9.1926.

4. On the next line or lines give the purpose of the experiment, *e.g.* "To allow phosphorus to fume in an enclosed space of air, and note what happens."

5. Omit the next line, *i.e.* leave a space between the statement of the experiment and the method.

6. Then tell briefly in your own words how you did the experiment, and what you observed.

7. Finish with a paragraph telling what you infer from the results of your observations.

ELEMENTARY GENERAL SCIENCE

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INTRODUCTION

SCIENCE—THE STUDY OF NATURE

When we study *Science* we really investigate the properties of the natural world around us. The different objects we perceive by our senses are called *bodies*. These bodies are composed of what we call *matter*. Matter is the stuff of which things are made. It is very difficult to define matter ; but anything that can be moved is made of matter. Some bodies are hard like a stone—these are *solids* ; some flow like water—these are *liquids* ; while others, like the air we feel when the wind blows, are *gases*. Thus we say matter exists in three states—solid, liquid, gas. We shall learn much about these different states of matter ; that is the study which we call Science.

In this study we investigate for ourselves and take little for granted. Things are not really what they seem. For example, it seems to us that when coal burns it goes into practically nothing. But Science shall teach us that no matter is destroyed in Nature. It is not sufficient to observe simply what happens : we must be continually asking ourselves : "Why did that happen ?" "What do we infer from this ?" Remember everything that happens has a cause. This is the first object we have in view in this study—finding the cause of things ; in other words, finding the truth.

And not only is the object of our study of Science to know the "wherefore and the why"; but, what is even more important, to teach us to think accurately, to reason accurately, and to express accurately what we mean. Therefore, our work must be systematic and methodical, and our notes neat and likewise methodical.

PART I—PRACTICAL

SECTION I

VOLUME—MASS—DENSITY

VOLUME

WE observe that some bodies are small and others are large. We say that a brick is larger than a threepenny piece. Now "in Rome one must do as the Romans do"; so in the Science room we must talk scientifically. Instead of saying that one body is larger than another we say exactly what we mean. Do we mean it is longer, or broader, or thicker? No: we really mean it takes up more room or space. The amount of space a body takes up we call its *volume*; and thus we speak of one body having a greater or less volume than another.

Now it is often difficult to say whether one body has a greater volume than another simply by looking at them; besides, such a method would be of little or no use, where, as in Science, accuracy is of such importance, accuracy of observation and of thought, as well as of speech. We must therefore have some standard or *unit* of comparison. The unit we use is the *cubic centimetre*, written c.c. You have already learned in the Mathematics class what a centimetre (cm.) is, and know it is a length of about two-fifths of an inch. Well, the amount of space taken up by a little cube, each of whose sides is 1 cm. long, is a c.c. Hence, if we can find the number of c.c. of space bodies occupy we can compare the volumes.

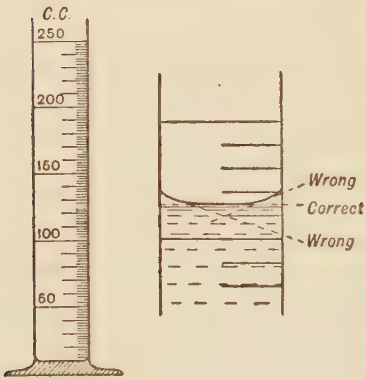
Similarly the volume of a cube whose edge measures 1 foot is a cubic foot.

If we make a c.c. of, say, plasticine, it is evident that, whether it remains in the shape of a cube, or whether we squeeze it into any shape, its volume will always be the same, *i.e.* it will always be 1 c.c. Similarly with any liquid. We ask the milkman for a pint of milk, and he measures it out

into a can which holds just a pint: *i.e.* the capacity of his measure is the same volume as a pint of milk, or a pint of any other liquid. The milkman's measuring vessel he uses for one volume only, but in Science we use vessels which can give us any suitable volume. Such a vessel is the one you are now going to examine.

EXPERIMENT 1. *To examine a measuring jar, and use it to find the volume of a heavy solid.*

Method. Examine the glass measuring jar, and describe it by answering the questions (1), (2), (3). Now pour water into the jar (4). Set it upright on the bench: and always read the jar in this position. Read the level of the bottom of the curve (called the *meniscus*). Note that it is important how you read the jar. Look at the reading with the water-level below the level of your eye; then with it above; and finally with it on the same level (5). Enter the volume in your record-book as below. Lower the solid by means of a thread into the water (6). Allow as little of the thread as possible to enter the water. Why? Read the water-level as before (7).



Gently withdraw the solid and note what happens. Repeat with a different volume of water in the jar. Record as below.

	Measuring jar.		Difference = Volume of solid.
	First reading.	Second reading.	
1	c.c.	c.c.	c.c.
2	c.c.	c.c.	c.c.
		Average . .	c.c.

Questions. 1. How is it graduated—from top to bottom ?

2. How many equal spaces are marked off between two successive numbers ?

3. What is the volume between any two consecutive marks ?

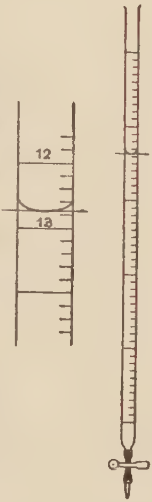
4. Is the surface of the water level ?

5. Are the readings the same ? Which will you take ?

6. What do you notice ?

7. Can you deduce the volume of the solid ?

The measuring jar you have already examined and used is probably graduated in 1 c.c. or 2 c.c. divisions, and for more accurate measurements we make use of narrower vessels ; for the narrower the vessel, the higher the water must rise to displace the same volume. Such a vessel is the burette, which is used clamped vertically.



Burette

EXPERIMENT 2. *To examine a burette, and use it to find the volume of a solid.*

Method. Proceed as in Experiment 1, and record your observations.

Note that we can use the measuring jar to tell us the volume of liquid actually in the jar ; but cannot use the burette to the same purpose. But we can tell accurately how much liquid has been run out of the burette. In fact, this is its chief use, hence the reason for its being graduated from top to bottom.

Questions. 1. In using the burette to find the volume of liquid run out, why is it necessary to make sure that the nozzle is at first full ?

2. Which of the measuring instruments, the jar or the burette, gives the more accurate determination of the volume ?

MASS

Let us consider the brick and the threepenny piece again. Not only has the former a greater volume, but it is much " heavier " than the latter. In the language of Science we say it has a greater *mass*. By the term *mass of a body* we mean *the amount of matter in it* ; and as with the finding of volumes we required a standard or unit, so in finding masses we require also a unit. You are already acquainted with the

pound (lb.); but in the Science room we use another unit, called the *gram* (gm.).

It is very easy to compare the mass of the brick with that of the threepenny piece; but to compare the masses of two threepenny pieces requires a more accurate method than simply lifting them. To do so we make use of a "see-saw." You have no doubt amused yourselves on a see-saw, and know that of the persons on the ends the one with the greater mass goes down and the other goes up. If both have the same mass, we say they *balance*, and the *beam* remains horizontal. The see-saw we use in the Science room is the *beam balance*. Its name explains its construction: and you have seen its use in the grocer's "*scales*."

To find the mass of a body we place it on one pan, and balance it by placing little pieces of metal whose mass we know on the other.

Examine the balance and observe the means taken to make it very sensitive. Also examine the box of "weights," and notice their arrangement, shape, and mass.

To preserve the balance from harm, and ensure accurate finding of masses the procedure adopted in the following experiments must be carefully observed.

EXPERIMENT 3. *To find the mass of* 1 *c.c. of water.*

Method (*a*). First find the mass of a small empty beaker. Raise the lever of the balance gently with the left hand to see if it is working properly: *i.e.* the pointer swinging an equal number of spaces on each side of the centre line of the scale. If it is not, let your teacher know and he will adjust it.

Place the empty beaker on the left-hand pan, and with the forceps lift a large weight out of the box, place it on the right-hand pan, and gently raise the lever again. (Never touch a weight with the fingers.) Observe whether it is too much or too little. Lower the lever. (*Never add or remove anything while the beam is swinging.*) If it is too much, remove it to its place in the box, and add the next lowest in mass; if too little, simply add the next and proceed as before, until the pointer is swinging evenly. The mass of the beaker will then be the same as the total mass on the right-hand pan.

Record each weight on the left-hand page of your note-book, as shown below, by observing the weights in the pan,

and checking by the empty spaces in the box, and then again by removing them to the box. (This method may be dispensed with after a few experiments—the total mass only being recorded.)

(*b*) Run into the empty beaker from a burette exactly 30 c.c. (say) of water, taking care that the nozzle is full before each reading.

(*c*) Find the mass of the beaker and the water as before.

Questions. 1. Can you find the mass of the water only ?
2. And the mass of 1 c.c. of water ?

N.B.—The average of all the results in the class should be made.

3. Do you think the result in any way remarkable ?

RECORD

Mass of beaker.		*Mass of beaker +30 c.c. water.*	
20	grams.	20	grams.
5	,,	20	,,
1	,,	10	,,
·2	,,	5	,,
·2	,,	1	,,
·05	,,	·2	,,
·01	,,	·2	,,
		·05	,,
		·02	,,
26·46	,,	56·47	,,

Mass of beaker $= 26{\cdot}46$ gm.
Mass of beaker +30 c.c. water $= 56{\cdot}47$,,

∴ Mass of 30 c.c. water $= 30{\cdot}01$,,

∴ Mass of 1 c.c. water $= \dfrac{30{\cdot}01}{30}$,,
$= 1{\cdot}00$,,

Note for Teacher. The second place of decimals may be got by using a decigram rider instead of the small weights, which are easily lost. Such a rider may be made by bending 5·43 cm. of aluminium wire, S.W.G. No. 20, into a shape similar to

DENSITY

Experiment 4. *To find the mass of* 1 *c.c. of* (1) *turpentine,* (2) *mercury.*

Method. Proceed as in Experiment 3, using only 10 c.c. of mercury (1), (2). Record as before.

Pour a little of each of the three liquids—water, turpentine, and mercury into the same vessel and shake them up together. Then let them stand for a time (3), (4).

Questions. 1. Do you observe any difference between the meniscus of mercury and that of water ?

2. How will you read the level of mercury ?
3. What happens ?
4. What do you infer ?

Experiment 5. *To find the density of a heavy solid.*

Method. Find (*a*) the mass by the balance, and (*b*) the volume by displacement. Record your observations as in Experiments 3 and 1, and calculate the density as under. (Simply place the solid on the left-hand pan of the balance.)

(*a*)	Mass of solid	=	gm.
(*b*)	First reading of measuring jar	=	c.c.
	Second ,, ,,	=	,,
∴	Volume of solid	=	,,
∴	c.c. have a mass of	gm.	
∴	1 c.c. has a mass of	,,	
∴	density of solid=	gm. per c.c.	

Experiment 6. *To find the capacity of a small bottle, and use it to find the density of a liquid.*

Method. Find mass of empty bottle ; fill it with water, making sure that it is dry on the outside, and find mass again (1), (2), (3).

Fill now with second liquid, and again find mass. Find mass of liquid (4).

Calculate the density of the liquid. Record as below.

N.B.—Small bottles suitable for this experiment, called density bottles, are sold, having a

Density bottle

stopper with a very narrow bore, to ensure a constant volume of liquid (see diagram above).

Questions. 1. What is the mass of the water ?
2. Can you deduce the volume of the water ?
3. What is the capacity of the bottle ?
4. What is the volume of the liquid ?

	Mass of bottle	=	gm.
	Mass of bottle+water	=	,,
∴	Mass of water	=	,,
∴	Volume of water	=	c.c.
∴	Capacity of bottle		,,
	Mass of bottle+liquid	=	gm.
	Mass of bottle	=	,,
∴	Mass of liquid	=	,,
and	Volume of liquid (same as volume of water)	=	c.c

$$\therefore \quad \text{Density of liquid} = \frac{\text{mass of liquid}}{\text{volume of liquid}} = \text{———}$$

i.e. gm. per c.c.
Class average = ,, ,,
Correct density = ,, ,,

SECTION II

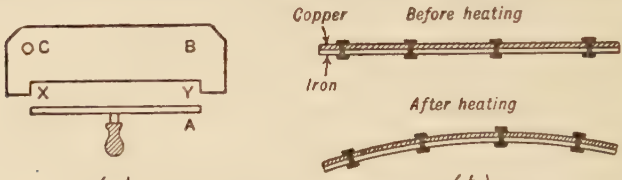
HEAT—EXPANSION—THERMOMETRY

From our everyday experience we are familiar with the idea of *heat* and *cold.* We "heat ourselves" before the fire; we "feel cold" during frost; we say steam is "hot" and ice is "cold." But what is the real meaning of these phrases ? We have noticed a space left between the lengths of rail on a railway, and wondered why they are not made to touch. We have seen glass vessels cracked by pouring hot water into them. We have observed that butter is hard in winter and soft in summer. The following experiments will teach us why.

EXPANSION

EXPERIMENT 7. *To find the effect of heat on solids.*

Method. (*a*) Take rod of metal A, and see if it fits into gauge B, between X and Y, also made of metal. Also see if



(*a*) (*b*)

rod will go into hole C in B. Now heat rod in a flame, and try again (1), (2), (3).

Now allow rod to cool, and test again if the rod fits the gauge (4).

(*b*) Take a strip of iron and a strip of copper of equal length, riveted together. Observe positions of the metals Heat them (5), (6), (7).

Allow the rods to cool and note what happens.

Questions. 1. Can you fit the rod into XY ?

2. What effect do you infer heat has had on the length of the rod ?

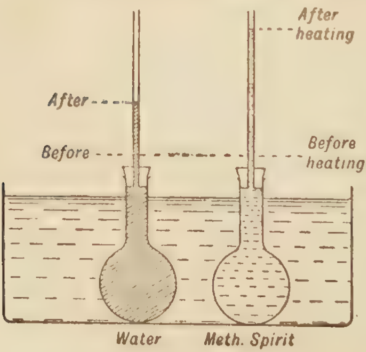
3. Has the heat affected the length only ?

4. What effect has the cooling ?

5. What happens ?

6. Which metal is the longer ?

7. What do you infer about different solids ?



EXPERIMENT 8. *To find the effect of heat on liquids.*

Method. Take two small bottles or flasks of same capacity, with corks to fit. Fill one with water and the other with methylated spirit. Fit into the corks long pieces of glass tubing of same bore (N.B.—*Always wet glass tubing or rod before putting into a cork*) so that the ends are flush with the ends of the

corks. Fit corks into flasks so that liquids rise to same height in tubes. Mark levels with gummed paper. Plunge them together into a basin of hot water, watching levels of liquids (1), (2), (3), (4).

Leave them for some time, and mark levels again (5), (6).

Take them out of the water and let them cool (7).

Questions. 1. What do you notice first ?

2. Can you explain ?

3. What happens next ?

4. How does the expansion of a liquid compare with the expansion of a solid ?

5. What do you infer about the expansions of different liquids ?

6. Which liquid rises higher ?

7. What follows ?

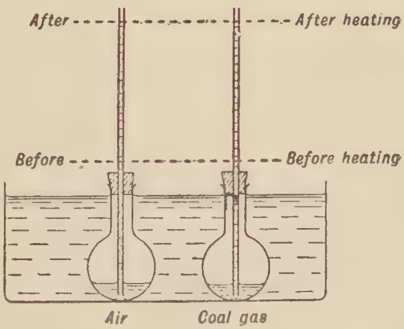
EXPERIMENT 9. *To find the effect of heat on gases.*

Method. Push an "empty" bottle mouth downwards into water (1).

Turn the bottle upright (2), (3).

If you turn on the gas tap, you can smell the gas (4).

Take two flasks as used in Experiment 8, and into each put same small quantity of water coloured with litmus or ink. Fill one with coal gas from the tap by attaching a rubber tube and bubbling the gas through the water for a time. Push glass tubes through the corks as before, so that on inserting corks liquids rise in tubes to same height. Mark levels. Plunge flasks into warm (not hot) water, and note as before all that happens (5), (6), (7), (8).



Remove flasks from water and note what happens.

Questions. 1. Why does the water not rise into the bottle to fill it ?

2. What is in the bubbles ?

3. What do you infer about an "empty" vessel ?

4. What do you learn about coal gas ?

5. How does the expansion of a gas compare with that of a liquid ?

6. Is there any difference in the levels of the water in the two tubes ?

7. What do you infer about the expansion of coal gas and air ?

8. How does the expansion of gases differ from that of solids and liquids ?

TEMPERATURE

EXPERIMENT 10. *To get an idea of " heat " and " temperature."*

Method. Put into each of two similar cans about a pint of cold water, taking care to have same quantity in each. Heat a pin in a flame until it is " red-hot," and also a lump of metal (say a 1-lb. weight) just "hot." Place the red-hot pin on the large piece of metal (1), (2). Heat it again. Feel water in each can, and into one plunge the red-hot pin and feel water once more (3).

Now plunge large piece of dull-hot metal into the water in the other can (4), (5).

Questions. 1. What happens to the pin ?

2. Which is hotter ?

3. Is the water any warmer ?

4. Is the water any hotter ?

5. Which gave out more heat—the pin or the lump of metal ?

THERMOMETRY

We are accustomed to tell whether a body is hot or cold simply by touching it with the hand ; but we cannot depend on the touch to compare temperatures. If we put the right hand into what we call cold water and the left hand into hot water, and then put both into lukewarm water, the lukewarm water will feel hot to the right hand and cold to the left, though it cannot be at two different temperatures at one and the same time. We must therefore have something we can depend on, some instrument more accurate than the sense of touch. Such an instrument is the *thermometer*—an instrument for measuring and comparing temperatures.

In an ordinary thermometer we make use of the fact that when the temperature of a liquid is raised its volume increases ; and if lowered, its volume decreases. Or, if it is made to expand or contract in a narrow tube its length increases or decreases. But before numerical measurements can be made we must have some " starting point " which is fixed and does

not vary. The starting point we use is the *temperature of melting ice*; ice melts at a certain degree of hotness or coldness. But again, what length of liquid in the narrow tube are we to take to represent one unit of temperature? Will we take an inch or a centimetre? It is evident that we cannot take any particular length, for a thick thread of liquid will not expand lengthwise so much as a thin one for the same rise of temperature, since the increase in volume is the same. We must therefore take another fixed temperature, and that is *the temperature of the steam from freely boiling water.*

We could, of course, take the difference between these two *fixed points*, as they are called, to be our unit; but that would be of little use, seeing the difference between them is so great. Different units are in use in different thermometers; that is, thermometers differ only in the unit used. Only two of these interest us, the *Centigrade* and the *Fahrenheit* thermometers, and the following experiments will enable us to understand how they have been made and graduated.

EXPERIMENT 11. *To find the temperature of melting ice.*

Method. Examine the Centigrade and the Fahrenheit thermometers. Read the temperatures on both. Put some small pieces of ice into a can, and immerse in them the bulbs of the thermometers. Describe what happens (1).

Constantly stir the ice with thermometers (2). Since the temperature of the air is higher than the temperature of the ice, heat must be passing from the air to the ice (3). Place the can on a tripod stand, and with a small flame supply heat to the can, constantly stirring (4), (5), (6).

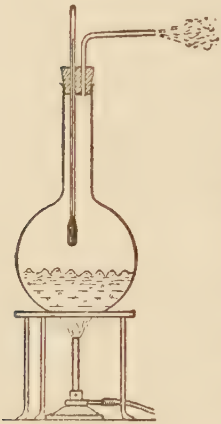
Questions. 1. Where does the mercury stop in each?
2. What is happening to the ice?
3. Why then is the temperature of the ice not rising?
4. Is there any rise in the temperature?
5. Where then is the heat going?
6. When only does the temperature begin to rise?

EXPERIMENT 12. *To find the temperature of the steam from boiling water.*

Method. Fit a flask, about half-full of water, with a two-holed stopper carrying a thermometer,* and a bent glass tube

* Some members of the class may use a Centigrade thermometer and others a Fahrenheit.

as in diagram. Arrange thermometer so that the bulb is 2 or 3 inches above the water. Place flask on a wire gauze on a tripod stand. Clamp it gently by the neck (1).



Heat the water (2).

Before the water boils observe the inside of the flask (3).

Boil the water (4), (5).

Read temperature when water is boiling freely, and keep it boiling steadily for a few minutes (6), (7). Repeat with a thermometer of the other kind.*

Questions. 1. Why must it not be clamped tightly ?

2. What do you notice about the thermometer ?

3. What do you notice collecting on the sides ?

4. What is in the bubbles rising through the water ?

5. Can you now tell what the little tube is for, and why it is bent?

6. Is there any change in the temperature ?

7. Where then is the heat going ?

The Making of a Thermometer

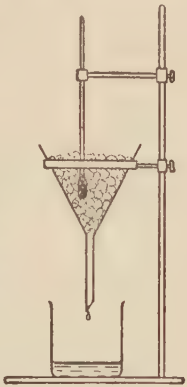
You will now be able to understand how a thermometer is made. A capillary tube, *i.e.* one having a very narrow bore (Latin : *capillus*, a hair), is taken, and after being tested to see that it is uniform in bore, a bulb is blown on the end. Mercury is introduced into it by attaching a small funnel by means of rubber tubing, and pouring mercury into the funnel (fig. *a*). The bulb, which, of course, contains air, is now heated, and some of the air is expelled up through the mercury in the funnel. On cooling, the air that is left contracts, and some mercury enters the bulb (fig. *b*). The bulb is again heated until the mercury boils, and thus its vapour expels all the air. On again cooling more mercury enters, and the process is repeated until all the air is expelled,

(a) (b) (c)

* See note, p. 13.

and the top of the tube then sealed. As it cools, the mercury contracts.

To graduate it, the bulb is plunged among small pieces of melting ice contained in a funnel, until the level of the mercury is steady for some time and the position marked 0° C. or 32° F. (M.P.). It is then placed in the steam from boiling water as in Experiment 12, and when steady for a time the position of the mercury is marked 100° C. or 212° F. (B.P.). To make the Centigrade thermometer, the length between the F.P. and the B.P. is divided into 100 equal divisions, and each division represents one Centigrade degree. For the Fahrenheit the space between the M.P. (or F.P.) and the B.P. is divided into 180 equal spaces, each division representing one Fahrenheit degree. The graduation may be continued below the F.P. (the temperature one degree below F.P. on the Centigrade scale being −1° C., and on the Fahrenheit scale 31° F.) and continued above the B.P.



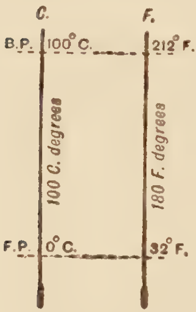
Historical. You have no doubt wondered why such out-of-the-way numbers as 32 and 212 should have been taken on the Fahrenheit scale, while 0 and 100 seem to be just what you should expect. Of the two thermometers the Fahrenheit is the older. It gets its name from the man who first (in 1714) used the scale—Gabriel Fahrenheit, who belonged originally to Dantzig. Fahrenheit thought that the temperature obtained by mixing snow and sal-ammoniac was the lowest obtainable, so he called it 0° or zero. His other fixed point he got from the temperature registered by putting the bulb into the mouth or the armpit of a healthy person, and to this he assigned the number 24. Finding the corresponding degree too large, he called this temperature 96° F., *i.e.* four times his original number. With these fixed points, then, it just happened that the temperature of melting ice was 32° F., and that of boiling water 212° F.

The Centigrade thermometer gets its name from the fact that there are 100 degrees or steps between the F.P. and the B.P. of water (Latin: *centum*=100: *gradus*=a step). It was first used by Anders Celsius, in Upsala, Sweden, in 1742.

The Centigrade thermometer is mostly used in scientific work everywhere, and on the Continent for general purposes; the Fahrenheit is oftener used in Britain for ordinary purposes and also in industry.

To Convert from One Scale to the Other

As we have seen, the thermometers differ only in the methods of graduation. The diagram will show that



100 Centigrade degrees = 180 Fahrenheit degrees.

$\therefore$ 1 C. degree $= \frac{180}{100}$ F. degree.

$= \frac{9}{5}$ F. degree.

and 1 F. degree $= \frac{5}{9}$ C. „

In converting from one scale to the other we reckon always from the F.P. Examples will illustrate.

Example 1. Convert 60° C. to the Fahrenheit scale.

60° C. means 60 Centigrade degrees above 0° C.

i.e. $60 \times \frac{9}{5}$ Fahrenheit degrees above F.P.

i.e. 108 Fahrenheit „ „ 32° F.

i.e. 140° F.

Example 2. What temperature Centigrade is equivalent to 95° F.?

95° F. means (95—32) Fahrenheit degrees above F.P.

i.e. 63 „ „ „ F.P.

i.e. $63 \times \frac{5}{9}$ Centigrade „ „ 0° C.

i.e. 35 „ „ „ 0° C.

i.e. 35° C.

Experiment 13. *To find the boiling point of any liquid (say alcohol).*

Method. Proceed as in *Experiment* 12.

N.B.—Be careful that the vapour from an inflammable liquid like alcohol does not catch fire. Keep the flame low and lead the vapour far away from it: therefore use a fairly long bent tube, sloping downwards.

Experiment 14. *To find the melting point of a solid—paraffin wax.*

Method. Melt some shavings of wax in a dish. Dip bulb of thermometer into the liquid. Withdraw thermometer so that a clear film of molten wax is on the bulb. Watch

the bulb, and as soon as it becomes dim, read temperature (1).

Now hold the bulb with the paraffin in cold water in a beaker, and gently heat the water. When dimness begins to disappear, again read temperature (2).

Take the mean of the two temperatures for the true M.P. (3).

Record as follows :—

Solidifying point = 52·1° C.
Liquefying point = 52·3° C.
∴ Melting point = 52·2° C.

Questions. 1. What is happening when it becomes dim ?
2. What is happening to make it clear again ?
3. Why ?

SECTION III

SOLUTION—EVAPORATION—CRYSTALLISATION—DISTILLATION

When we put a spoonful of sugar into our tea it seems to disappear ; but we know it has not been lost, because by tasting the tea we detect its presence in the liquid. In fact, we cannot taste sugar itself until it goes through the same process that it does when put into the tea, although to a small extent (in the mouth). We have most of us, too, had an unpleasant mouthful of sea water while bathing, and have wondered where the ocean salt came from. We have seen jam which has been left open to the air become sugary on the top. We have found that we may keep ink in a bottle for a considerable time, yet when it is spilt it soon "dries up." These are the problems we are now going to study in this section. Incidentally we shall learn why we drink tea out of a cup and not out of a plate, and why we eat soup out of a plate and not out of a bowl ; why we use paraffin to clean windows, and how petrol takes stains out of cloth ; how we can get water even for drinking from sea water, and why rain which comes from the sea does not taste salt.

SOLUTION

Experiment 15. *To find what happens when alum is shaken up with water.*

Method.—Into a test-tube put water to a depth of about 3 inches. Add a small pinch of powdered alum, and putting thumb over mouth of test-tube, shake vigorously (1).

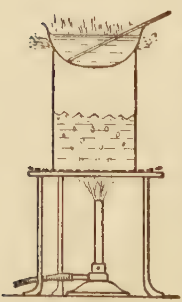
Add another pinch and shake again (2). Continue as before, adding small quantities until a little is left at bottom of test-tube and will not disappear after considerable shaking. Now warm bottom of test-tube (3). Add a little more alum and see if it also disappears. If it does not, heat further until it does. Cool tube by dipping it into cold water, or allow cold water to run down outside (Do not let any water into tube) (4), (5). Examine the small particles closely, by help of a lens if possible (6).

Questions. 1. What happens to the alum ?
2. Does it disappear also ?
3. What happens ?
4. What do you see ?
5. What do you infer ?—does more alum disappear in hot water or in cold ?
6. Can you tell anything about the shape of the particles ?

EVAPORATION

Experiment 16. *To find if we can recover the solute from a solution.*

Method. *N.B.*—Enter results as under.



Find mass of a small porcelain basin, with a small glass rod, and a watch-glass large enough to cover basin. Pour into basin about 15 or 20 c.c. water, and again find mass. Put on watch-glass a small quantity of salt (a large pinch will do), and find mass of the lot. Now pour salt into water, and stir with rod until salt is dissolved. Leave rod in basin. Find mass once more (1), (2).

Into a can put some water and boil. This is what we call a steam bath (see fig.). Place basin with solution over mouth of the bath to heat solution (*N.B.*—See that there is always water in the bath) (3).

When you think the substance in the basin is quite dry, lift it off, dry bottom of basin with a clean duster, and find mass of whole again (4).

Replace on bath for a few minutes and dry and reweigh. Repeat till two consecutive weighings are same. The substance left in basin is called the *residue* (5).

Mass of basin + watch-glass + rod	=	gm.	
" " " + " " + " + water	=	"	
" " " + " " + " + " + salt	=	"	
∴ Mass of salt	=	"	
" " basin + watch-glass + rod + solution	=	"	
" " " + " " + " + residue	=	"	} same.
" " " + " " + " + "	=	"	
∴ Mass of residue	=	"	

Questions. 1. Is there any difference ?

2. Is anything lost when a substance dissolves ?

3. What do you notice about the volume of the solution as it is being heated ?

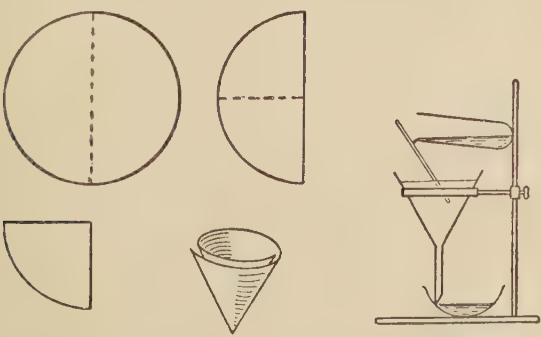
4. How will you make sure that all the water has disappeared from the basin ?

5. How does the mass of the residue compare with the mass of the salt taken ?

FILTRATION

EXPERIMENT 17. *To separate a soluble from an insoluble substance (say salt and sand).*

Method. Shake up a little sand in water (1), (2). Allow to settle: pour some of the liquid into an evaporating basin,



and evaporate to dryness (3), (4). Heat about 20 c.c. water in a test-tube. Add mixture of salt and sand, and shake well, and heat (5).

Take a filter paper and fold it to form a semicircle; then again to form a quadrant (see fig.). Open it so that you have three parts on one side and one on the other, and form it into shape of a cone. Place it in a funnel; wet it with a little water, so that it sticks to sides of funnel. Put funnel in a stand, with an evaporating basin underneath, so that the tube of funnel touches inside of basin. Pour the liquid down a glass rod into middle of paper as shown in figure. Be careful not to run in too much liquid: keep level about 1 cm. from top of paper (6). Wash residue on filter paper with warm water, and catch in basin. Examine residue (7). Evaporate solution as before (8).

Questions. 1. Does it dissolve ?
2. How would you make sure ?
3. Is there any residue ?
4. What do you infer about the solubility of sand ?
5. What is now in the test-tube ?
6. What comes through the paper ?
7. What is it ?
8. What is the residue in the basin ?

CRYSTALLISATION

EXPERIMENT 18. *To separate two soluble substances (say alum and copper sulphate).*

Method. Powder in a mortar some blue copper sulphate and about half its mass of alum. Heat about 70 c.c. water in a beaker. Add powder to warm water in small quantities, with constant stirring till solution is saturated. Filter into a crystallising dish and set aside till next lesson, and examine (1).

Decant liquid into another dish and leave aside again till the following lesson. Now examine again (2). Pick out some crystals of each and redissolve separately in a little warm water, and allow to cool.

If no solid has separated out the first time, evaporate off some water and set aside. If you cannot pick out two different substances, redissolve whole in warm water and set aside. Next lesson examine again (3).

If you have some well-formed crystals of each draw a sketch of them; if they are too small, examine with a lens, or under a microscope if one is available.

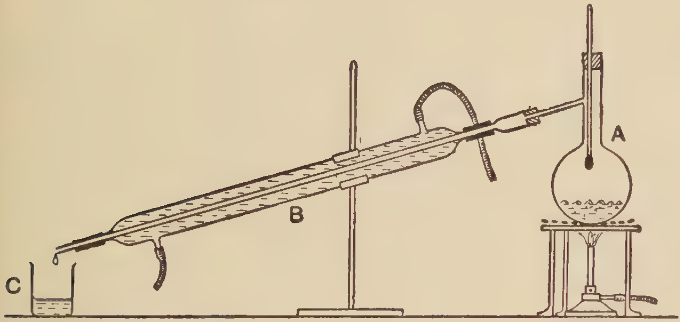
Questions. 1. On examining next lesson what do you find ?
2. Can you detect two different substances ?
3. Do you find any crystals ? How many different kinds ?

DISTILLATION

EXPERIMENT 19. *To recover the solvent from a solution.*

Method. The apparatus consists essentially of three parts: (A) the boiler, (B) the condenser, (C) the receiver.

(A) consists of a flask with a side tube (called a Würtz flask), fitted with a cork carrying a thermometer. Into it put a solution of copper sulphate, which you have seen is coloured



blue. Arrange thermometer so that it is well out of liquid. Fit, by means of a cork, side tube into inner tube of (B).

(B), the *Liebig condenser*, consists of a long tube surrounded by a wider tube (called the jacket tube), through which circulates cold water from the tap, passing in at lower end and out at top. Can you explain why ?

(C) consists solely of a beaker or flask placed at end of tube of condenser to collect liquid.

Fit up as in diagram, and heat solution to boiling point. Read temperature, and note what is happening in condenser and in receiver. What is colour of liquid in receiver ? What is the liquid ? Continue process until there is a little solution left in flask.

EXPERIMENT 20. *To separate two liquids, say, water and alcohol.*

Method. Fit up distillation apparatus used in Experi-

ment 19. Put liquid into flask and heat. Watch the thermometer (1), (2).

Smell first small quantity distilled. See if a little of it burns in a basin (3), (4).

Collect in one receiver liquid distilling, while the temperature rises through about 3° only. Remove this receiver and place in a second one (5).

Collect distillate till temperature reaches about 96° C. Smell it, and see if a small quantity will burn as before (6), (7).

Remove second receiver and place in a third. Collect distillate till only a little liquid is left in flask. Smell third quantity distilled, and see if it burns (8).

Questions. 1. When does the liquid begin to boil ?
2. Does the temperature remain steady ?
3. Is there any residue in the basin ?
4. What is the liquid ?
5. Does the temperature still rise ?—rapidly or slowly ?
6. Is there any residue ?
7. What does the distillate consist of ?
8. What is the liquid ?

SECTION IV

THE CHEMISTRY OF THE AIR—RUSTING—BURNING

AIR: A MATERIAL SUBSTANCE

We have already seen that air has properties. It occupies space and if heated it expands, if cooled it contracts, just like a solid or liquid which we can feel and handle easily. Moreover, in Experiment 12 we observed that it dissolves in water and may be expelled from the water by boiling. We are led, therefore, to understand that air is a material substance ; that is, it is composed of matter, and we proceed to find out more about air. Hitherto our study has been only the *physical* properties of bodies. We have not been concerned about what the various substances are made of ; that is, we have not studied their composition. This is what we are now to study. We shall inquire about the composition of the air,

and at the same time find what takes place when things burn, when we breathe, when iron rusts; and why railings are painted, why an apple turns brown when peeled and left in the air, why cooked food tastes differently from raw food.

EXPERIMENT 21. *To find if air has mass.*

Method. Take a round-bottomed flask and fit it with a rubber stopper carrying a small piece of glass tubing with a rubber tubing attached, on which is a clip (see fig.). Find the mass. If flask is too large to lie on pan of balance, stand it upright, supported by a thread from the stirrup.

Into the rubber tube put another small piece of glass tubing. Open clip, and suck as much air as possible out of flask. While still sucking close clip. Remove small glass tube and again find mass (1), (2). Very gently press clip (3).

Questions. 1. Is it greater or less than before?
2. What do you infer about air?
3. What do you hear?

THE RUSTING OF IRON

EXPERIMENT 22. *To find if there is any change in mass when iron rusts.*

Method. Examine some coarse iron filings. Note especially (*a*) the colour; (*b*) hammer some (1); (*c*) draw a magnet through it (2).

Find mass of a crucible with a small quantity of fine iron filings. Moisten filings thoroughly with a little water, and set aside till next lesson.

Examine filings after a day or two (3). Now we found mass of crucible with iron only; hence heat crucible and contents till red hot to drive off any water remaining. (The crucible is supported on a pipe-clay triangle on the tripod stand.) Cool and again find mass (4), (5), (6).

Scrape filings out of crucible and examine them. Note (*a*) the colour; (*b*) hammer some (7); (*c*) draw a magnet through the rusted iron (8). Record as under.

	Mass of crucible+iron	=	gm.
	,, ,, +iron rust	=	,,
∴	Gain (or loss) in mass	=	,,

Questions. 1. Is it hard ? Can you flatten it out ?
2. What happens to the filings ?
3. What has happened to the iron ?
4. Is there a gain or a loss of mass ?
5. What do you infer happens when iron rusts ?
6. Where has the increase come from ?
7. Is the rust hard like iron ?
8. Is the rust drawn to the magnet ?
9. Would you say that rust is the same substance as iron ?

N.B.—The three following experiments, which take some time to complete, may be conveniently proceeded with during the same lesson to save time.

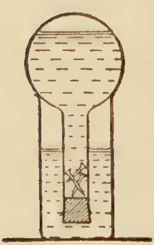
Experiment 23. *To find if iron will rust in air without water.*

Method. Place some polished iron wire (or some bright French nails) on a watch-glass and put into a desiccator; this is a vessel containing a substance (*e.g.* strong sulphuric acid or calcium chloride) which has the property of attracting every trace of moisture in the vessel, if kept sealed, and thus keeping the air inside perfectly free from water vapour. (A wide-mouthed bottle, with ground-glass stopper, and calcium chloride will serve the purpose.) Place the lid on firmly, and leave for a length of time. Examine iron each Science day (1). After some weeks take out iron and leave it in damp air (2), (3).

Questions. 1. Does the iron show any signs of rusting ?
2. Does it now rust ?
3. Is water necessary to rust iron ?

Experiment 24. *To find if iron will rust in water without air.*

Method. Fill a round-bottomed flask up to the neck with distilled water, and boil the water, clamping flask over a gauze (1). Keep boiling for about fifteen minutes. Also boil a large beaker nearly full of water for a similar length of time.

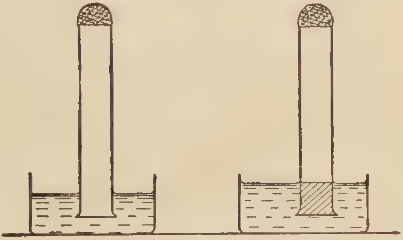


As quickly as possible slip a few brightly polished French nails (or iron wire) into flask, fit it with a tightly fitting rubber stopper, and invert it into the beaker of water as in figure (2). Examine the iron each science day (3). Remove flask, clamp upright, take out stopper (4), and leave for a few days (5), (6), (7).

Questions. 1. Why is the water boiled ?
2. What is the purpose of the water in the beaker ?
3. Is there any sign of rust ?
4. Is it easy to do ?
5. Why is the stopper removed ?
6. Does the iron rust now ?
7. Is air necessary before the iron rusts ?

EXPERIMENT 25. *To allow iron to rust in a confined space of air, and note what happens.*

Method. Into the bottom of a large test-tube put some coarse iron filings and fix them in position by placing in a piece of wire gauze. Moisten the filings by a little water. Invert test-tube mouth downwards in a basin of water so that no air can get in or out (1). Clamp test-tube in water as in figure, and leave till next lesson. Next day examine (2), (3), (4). Mark level of water by a thread or a piece of gummed paper, and leave again till next day (5). Leave until water rises no higher. Now slip a glass disc under mouth of test-tube, and lift it out with water already in, so that no more air enters test-tube. Turn it upright so that the water is in bottom of tube, with the air above. Light a taper, and, removing glass disc, plunge lighted taper into air in test-tube (6).



Plunge a lighted taper into a similar test-tube full of "ordinary" air (7), (8).

Measure (*a*) volume of air originally in tube ; (*b*) volume of air that had disappeared. (This may be done by pouring water into tube and measuring with measuring jar.) Calculate the fraction (*b*) is of (*a*), as under. Compare your result with your neighbour's.

	Volume of air originally in tube	=	c.c.
	,, ,, remaining	=	,,
∴	,, ,, used up	=	,,
∴	fraction of air used up when iron rusts	=	————

Questions. 1. What is the volume of the air enclosed in the test-tube ?

2. What do you notice about the iron filings ?
3. What do you observe about the level of the water ?
4. Is any air used up when iron rusts ?
5. Is there any change again in the water level ?
6. What happens ?
7. Would you say that the air left in the test-tube where iron rusts is "ordinary" air ?
8. How many different gases do you think are in the air ?

THE FUMING OF PHOSPHORUS

CAUTION. *Phosphorus must not be touched with the fingers, but be lifted by means of crucible tongs.*

EXPERIMENT 26. *To allow phosphorus to fume in an enclosed space of air, and note what happens.*

Method. Take a long tube closed at one end—a burette will do. Half fill a gas jar with water. Make a loop on a long copper wire. Into a small test-tube put some water and a piece of phosphorus. Gently warm the water in test-tube until phosphorus melts. Dip the loop on wire into the molten phosphorus, and cool phosphorus by running cold water over outside of tube until phosphorus solidifies. Withdraw wire with phosphorus and quickly insert it into burette, and invert it into water in gas jar, arranging wire so that burette stands as in figure (1).

Leave for a few days, examining frequently (2), (3), (4). Mark level of water each day as in Experiment 25 (5), (6).

Now pour water into jar to level of water in burette, and mark level. Withdraw wire with phosphorus, still keeping mouth of burette under water so that no air escapes or enters. Close burette with thumb and lift out. Plunge a lighted taper into burette (7), (8).

Calculate as in last experiment what fraction the air that has disappeared is of the original air (9).

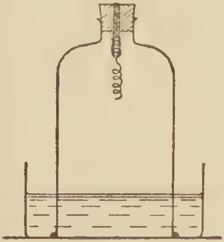
Questions. 1. What is the volume of air enclosed ?
2. What do you observe happens to the phosphorus ?
3. Is there any difference in the level of the water ?
4. Is air used up when phosphorus fumes ?
5. Does water rise to the top of the burette ?

6. Has all the phosphorus disappeared ?
7. What happens ?
8. Is the remaining air "ordinary" air ?
9. Do you find any connection between the rusting of iron and the fuming of phosphorus ?

BURNING

EXPERIMENT 27. *To burn magnesium in a confined space of air, and note what happens.*

Method. Place a bell jar in a basin of water, and arrange a thread round jar to mark level of water. Into a rubber stopper which fits tightly into the neck of bell jar fix a piece of glass rod, round which twist a short length of copper wire. Attach a piece of magnesium ribbon made into a spiral, so that it can slip through neck easily. Ignite magnesium and quickly plunge it into jar, fitting cork tightly (1). Wait until temperature returns to its original, and pour water into basin until same height as in the jar, and mark with a second thread (2).



Make sure that there is still some magnesium left unburnt (3).

Remove stopper, and quickly plunge into jar a lighted taper (4).

Replace stopper, invert jar, and pour in water up to first thread. Measure volume of water in a measuring jar. This gives (*a*) volume of air in jar before burning. Measure also (*b*) volume between threads : this is volume of air used up. Calculate, as before, fraction (*b*) is of (*a*) (5), (6).

Questions. 1. Does the water level in the jar rise or fall at first ? Explain why.

2. Is any air used up ?
3. Why did it not all burn ?
4. What happens ? Is it ordinary air that is left ?
5. Is there any connection between rusting, fuming, and burning ?
6. Can you infer anything about the composition of air ?

INDESTRUCTIBILITY OF MATTER

EXPERIMENT 28. *To rust iron filings in a tightly stoppered flask and find if there is any change of mass.*

Method. Put into a round-bottomed flask a quantity of iron filings. Add a little water to moisten them. Tightly fit in mouth a rubber stopper, and find mass of whole. Set aside until next lesson (1). Again find mass (2), (3).

Try to remove stopper (4). Remove stopper and then replace it. Again find mass (5), (6).

Questions. 1. What has happened to the iron ?
2. Is there any difference ?
3. Can you infer anything from the result ?
4. Can you do it easily ?
5. Is there any difference ?
6. Where does the increase come from ?

EXPERIMENT 29. *To find the effect of heating metals strongly in the air.*

Note.—In the following experiment various members of the class should take different metals—zinc, tin, lead, copper foil, iron filings, magnesium ribbon.

Method. Examine metal given you, noting its colour, metallic lustre, metallic ring, whether flexible, etc. Put into a crucible small pieces of the metal, and find mass, along with a knitting needle as a stirrer. (In the case of magnesium have also crucible lid.) Set crucible on a pipe clay triangle on a tripod stand, and heat as strongly as you can (1), (2). Constantly stir with needle.

In the case of magnesium lift lid occasionally with tongs (3). Immediately it glows clap on lid so as not to lose any of the smoke.

When no further change is observed, cool and again find mass (4). Compare your results with your neighbours' (5).

Questions. 1. Is there any change in state ? *i.e.* does it melt ?
2. Does it change in colour ?
3. Why ?
4. What do you infer ?
5. Has the ash any of the properties of the metal ?

OXYGEN

EXPERIMENT 30. *To find the effect of heat on mercury calx.*

Method. Put a small quantity of the red powder into a hard glass test-tube. Heat gently in flame, and when any change is seen remove immediately from flame and allow to cool (1), (2), (3).

Now heat more strongly (4).

Light a splinter of wood (a piece of pencil—cedar wood—will do) and blow out flame, leaving end glowing. Hold glowing end in mouth of test-tube, still heating calx (5), (6). Withdraw splinter, again blow out, and repeat.

Examine sides of tube (7), (8).

Questions. 1. What change do you notice at first ?
2. Does it return to its former appearance ?
3. What kind of change had it undergone ?
4. Do you observe any further change ?
5. What happens to the glowing splinter ?
6. Is it ordinary air in the tube ?
7. What do you see ? Can you tell what it is ?
8. How many different substances have you got from the one substance mercury calx ?

We have seen that in the rusting of iron, the fuming of phosphorus, and the burning of magnesium in an enclosed space, the process came to an end when all the oxygen in the space had been exhausted, not because the iron, the phosphorus, or the magnesium had been all used up. This would suggest that the quantity of oxygen present combined with only a certain quantity of the other element. We proceed to find out if this is the case.

EXPERIMENT 31. *To decompose a certain mass of mercury calx, and compare the mass of mercury with the mass of oxygen.*

Method. Find mass of a hard glass test-tube by attaching a thread to the lip and hanging on the stirrup of the balance. Add a small quantity of mercury calx and again find mass. Heat strongly until no more oxygen is being given off. Take care not to lose any of the mercury. Again find mass (1), (2). Calculate mass of oxygen in 100 grams of mercury calx. Enter your results as under. Compare your result with your neighbours' (3).

	Mass of test-tube	=	gm.
	,, ,, +mercury calx	=	,,
∴	,, mercury calx	=	,,
	,, test-tube+mercury	=	,,
∴	,, oxygen	=	,,

Hence	gm. mercury calx contain	gm. oxygen.
∴ 100 gm.	,, ,,	×100 gm. oxygen
	i.e.	gm. oxygen.
and ∴ 100 gm.	,, ,,	gm. mercury.

These amounts of the elements in 100 gm. of a compound are what is meant in Chemistry by the *percentage composition* of the compound.

Questions. 1. Is there any difference ?
2. What is it due to ?
3. Is there any similarity among the results ?

SECTION V

THE CHEMISTRY OF THE AIR—OXYGEN—NITROGEN

Experiment 32. *To find the effect of heating* (a) *potassium chlorate* ; (b) *manganese dioxide.*

Method. (*a*) Put into a hard glass test-tube, to a depth of about half an inch, some potassium chlorate, and heat gently. Stop heating when you observe any change (1), (2), (3).

Heat further (4). Cool and see what occurs (5). Heat more strongly and describe any change. Test with a glowing splinter (6), (7), (8).

Continue to heat until no more gas is given off (9).

Describe appearance of residue (10).

(*b*) Repeat with manganese dioxide (11).

Questions. 1. Do you hear anything ?
2. What causes the noise ?
3. What kind of change has taken place ?
4. What now happens ?
5. Has the substance changed ?
6. What gas is evolved ?

7. What is happening to the chlorate ?
8. What kind of change now ?
9. Is there any residue in the tube ?
10. Can it be potassium chlorate ? Why ?
11. Can you detect any gas being given off ?

EXPERIMENT 33. *To find the effect of adding manganese dioxide to fused potassium chlorate.*

Method. In an ordinary test-tube heat gently a little potassium chlorate just until it fuses. (Do not heat until it effervesces.) Test for oxygen (1). Now add a pinch of manganese dioxide to the fused potassium chlorate without further heating, and immediately test for oxygen (2), (3), (4).

Questions. 1. Is there any oxygen evolved ?
2. Is any oxygen given off now ?
3. From which of the two substances do you think the oxygen comes ?
4. What is the use of the manganese dioxide ?

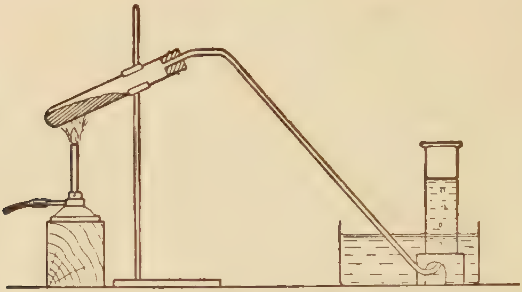
PREPARATION OF OXYGEN

We are now in a position to get a large supply of oxygen and to examine its properties. We have no doubt made up our minds about some of these. We have seen that a glowing splinter of wood bursts into flame in it. But how are we going to catch the gas in order to examine it ? It is easy to handle a solid or contain a liquid in a vessel; but how to get a gas. The method employed in the following experiment is a common one.

EXPERIMENT 34. *To prepare oxygen and examine some of its properties.*

Method. Heat in a porcelain basin some manganese dioxide to drive off any moisture in it. Grind up in a mortar a quantity of potassium chlorate crystals and about a quarter of its bulk of manganese dioxide. (This powder is sometimes called "oxygen mixture.") Put some of the powder into a test-tube to fill about one-third, and arrange it clamped in a sloping position as in the figure. Be careful not to clamp it too tightly. Fit in a tightly fitting, one-holed rubber stopper, carrying a delivery tube (see figure), allowing end to dip under surface of water in a basin (called a pneumatic trough) through hole in a bee-hive shelf. See that level of water is at least

an inch above bee-hive. Fill a gas jar with water by putting it on its side in water and lifting it inverted, keeping mouth

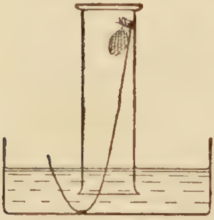


under water so as not to let air in. Heat tube gently and allow first bubbles to escape. (What do they consist of ?) When bubbles are coming freely, lift jar on to bee-hive, keeping mouth still under water. The gas rises into jar and displaces water. Do not heat unless gas comes too slowly. When jar is full of gas, slip a glass cover over mouth under water and press it against jar. Lift it out and stand it upwards on bench with cover on. Prepare eight jars of gas and perform following tests with them.

N.B.—Remove delivery tube first from test-tube. (Why ?) Observe that the gas is clear, colourless. Smell it.

First jar. Remove cover and plunge in a glowing splinter (1).

Second jar. Wrap some iron filings in a piece of muslin and tie them to the end of a stout wire. Invert jar in water. Removing cover under water, push the filings up into the oxygen without allowing any gas to escape. Leave inverted (as in figure) till next day (2), (3).



Third jar. Put a small piece of phosphorus in a deflagrating spoon, set fire to it by touching with a hot wire, and plunge into the gas (4). (*N.B.*—If any phosphorus is left on the spoon, let it burn away in the fume cupboard.)

Fourth jar. Hold a small piece of magnesium in tongs. Heat it till it catches fire, and immediately plunge into gas (5). Compare ash with calx formed when magnesium burned in air

Fifth jar. Put in moist pieces of red and of blue litmus paper (6).

Sixth jar. Slide cover a little to the side, and pour in a small quantity of air-free water (see Experiment 24). Immediately replace cover and shake vigorously. Invert into a basin of water and carefully slide cover a little to the side again (7), (8).

Seventh jar. Invert jar over a jar of air so that they are mouth to mouth, keeping the gases separated by cover. Remove cover, still keeping them mouth to mouth. After an instant plunge a glowing splinter of wood into bottom jar (9), (10).

Eighth jar. Remove cover; add a little lime water; replace cover, and shake up (11).

Questions. 1. What happens ?
2. What has happened ?
3. Is this what you had expected ?
4. Is there any difference in the flame when plunged in ?
5. Does it burn any more vigorously ?
6. Is there any change in the colour ?
7. Does any more water enter the jar ?
8. What do you infer about the solubility of oxygen in water ?
9. What is now in this jar ?
10. What do you infer about the density of oxygen ?
11. Is there any difference in the lime water?

ACIDS AND ALKALIES

EXPERIMENT 35. *To find the action of different substances on litmus.*

Caution.—Do not drop any of the following substances on the clothes.

Method. Litmus is a blue dye got from certain plants—a kind of lichen.

(*a*) Pour a small quantity of dilute sulphuric acid into a clean test-tube and add a few drops of litmus solution (1).

Repeat with dilute hydrochloric acid, nitric acid, vinegar.

(*b*) Take a small quantity of caustic soda solution in another test-tube, and add a few drops of litmus solution (2).

Repeat with caustic potash and ammonia.

(*c*) Take some more blue litmus solution in another clean test-tube. Add a few drops of acid and get a change of colour; and now add some caustic soda solution to *same* solution, a drop at a time (3).

Repeat with caustic potash and ammonia instead of caustic soda.

(*d*) Take two test-tubes. Into one put blue litmus and into the other some acidified litmus. Add to each some common salt solution or some sugar solution (4), (5).

Questions. 1. What happens ?
2. Is there any change ?
3. What happens ?
4. Is there any change ?
5. How many different classes of substances have you used as regards their action on litmus ?

OXIDES

On examining the list of elements we see that a number of them are what are known as *metals*—iron, copper, gold, silver, etc. They have somewhat similar properties.

1. They are all solids (with the exception of mercury).
2. When struck or let fall, they have a peculiar sound, called *metallic ring*.
3. They can be polished (*i.e.* they have *metallic lustre*).
4. They can be hammered or rolled into sheets when hot (*i.e.* they are *malleable*).
5. They can be drawn into wire (*i.e.* they are *ductile*).
6. They are mostly dense elements.

The other elements—non-metals—have usually opposite properties to these. But there is no hard-and-fast division between the two classes as regards physical properties. In the following experiment we shall study one very important chemical difference.

Experiment 36.—*To burn elements in oxygen and examine the products.*

Method. Prepare eight jars of oxygen as in Experiment 34, and burn one of the following elements in each jar :—

Carbon, sulphur, phosphorus, sodium, calcium. Put a small piece of each (about the size of a pea) into a clean deflagrating spoon (see figure) and hold it in a flame until it catches fire. Immediately plunge into the gas. Describe what happens. Describe also appearance of each oxide formed. Withdraw spoon. To those which have formed gaseous oxides add a

little water; replace cover, shake up; then add pieces of red and of blue litmus paper. If the oxide is solid add it to pieces of red and of blue litmus paper. Tell colour changes.

Magnesium, iron, copper. To burn these hang some magnesium ribbon and fine iron and copper wire from the spoon. Into the jar put a piece of wet filter paper. Ignite each element in turn and immediately plunge into a jar of oxygen. Describe and test with litmus as before.

Note (*a*) which of above elements are metals and which non-metals; (*b*) which oxides give acids; (*c*) which oxides give alkalies; (*d*) which oxides are neutral to litmus.

Arrange your observations in a table as follows:—

Element.	Metal or non-metal.	Description of action.	Description of oxide.	Acid or alkaline or neutral in water.

Question. Do you observe any difference between the oxides of metals and the oxides of non-metals?

NITROGEN

We have already (in the rusting of iron, the fuming of phosphorus, and the burning of magnesium in an enclosed space of air) prepared nitrogen from the air, and seen its most important property, that it extinguishes a lighted taper. We shall prepare it now in larger quantities and make a further examination of its properties.

EXPERIMENT 37. *To prepare nitrogen and examine its properties further.*

Method. (*a*) Fit up apparatus as shown in figure. A is a combustion tube containing copper turnings. B is a large bottle of water fitted with stopper with two holes, one carrying a glass tube reaching almost to the bottom. It is attached by

means of a piece of rubber tubing C to a similar tube D. These two tubes are filled with water at beginning, and a screw clip is fastened to C. The rest of apparatus is easily understood from

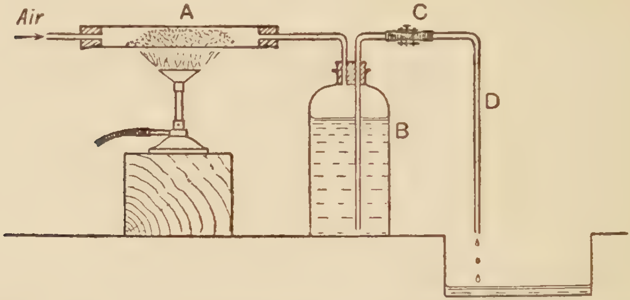
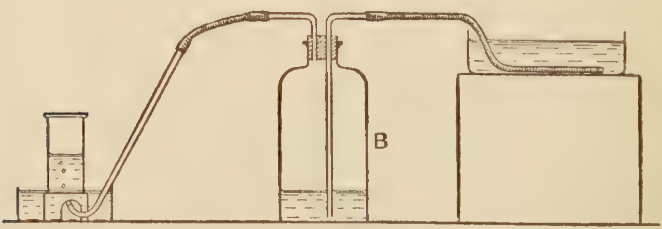


figure. Heat copper in combustion tube, and open clip C a little, so that water just trickles out by D into a basin or sink. As water flows out, a corresponding volume of air is sucked in through A over copper.

Questions. 1. What happens to the copper ?
2. What gas is collected in B ?

(*b*) When you have sufficient gas, close clip C.

Detach combustion tube from the apparatus and fix on a delivery tube to collect gas over water as in Experiment 34 (see figure). Also remove tube D, and fasten a rubber tube



from water tap, or raise a basin of water above level of B and allow water to flow into B, thus displacing gas in B. Collect six jars of the gas.

Describe the appearance of the gas. Smell it.

First jar. Plunge in a lighted taper (1).

Second jar. Add wet pieces of red and of blue litmus (2).

Third jar. Add a little air-free water and shake up. Open under water (3).

Fourth jar. Leave upright open on bench: and

Fifth jar. Invert open on a tripod stand for half a minute. Test each with a lighted taper (4).

Sixth jar. Add lime water and shake (5).

Write out as you did in the case of oxygen a summary of the properties of nitrogen.

Questions. 1. Does the gas burn or does it support combustion?

2. Is there any effect?
3. Is the gas soluble?
4. What do you infer about the density of the gas?
5. Is there any effect?

MIXTURES AND COMPOUNDS

EXPERIMENT 38. *To compare the properties of a mixture of iron and sulphur with the properties of a compound of iron and sulphur.*

Method. *A.* Examine some iron filings. (*a*) Note the colour; (*b*) throw some into water (1); (*c*) draw a magnet through some (2).

Do the same three things with flowers of sulphur (3).

Try to predict (*a*) colour of the powder formed by grinding some iron filings with sulphur; (*b*) effect of throwing a pinch of the mixture into water; (*c*) effect of drawing a magnet through the mixture.

Now make such a powder (4).

Find if your predictions are true (5).

Examine the powder closely, first with naked eye and then with a lens (6), (7).

Divide your mixture into three parts and put one aside. To another portion add more sulphur, and mix. To the third add more iron filings, and mix (8).

B. Now put the first portion into a dry test-tube and heat gently. Whenever a glow begins, remove at once from flame and observe what happens (9). When action is finished, heat whole tube strongly from closed end to other, and allow to cool.

Remove the hard mass (break tube if necessary, and lift out any pieces of glass). You have now a compound of iron and sulphur (10).

Grind it up, and perform same tests as you did with mixture in *A* (*a*), (11); (*b*) throw a pinch into water (12); (*c*) draw a magnet through the substance (13).

Examine with a lens (14), (15).

Questions. 1. Do they float or sink ?

2. What happens ?

3. Are there any resemblances ?

4. Is there any change of temperature when you simply mix them ?

5. Could you separate the iron from the sulphur without a chemical change ?

6. Can you distinguish the individual substances ?

7. If your fingers were small enough, or if you had a suitable instrument to pick out only one single particle, what would it be ?

8. Is there any difference to the general properties of the mixture ?

9. What kind of change is taking place ?

10. Can you give the name of the compound ?

11. Does it resemble in colour either the sulphur or the iron ?

12. Can you separate the iron from the sulphur in this way ?

13. Could you have predicted these properties from those of iron and sulphur ?

14. Can you see any particles of iron or sulphur ?

15. If you could pick out one single particle of the substance, what would it be ?

Experiment 39. *To add four volumes of nitrogen to one volume of oxygen, and examine the product.*

Method. Collect in a measuring jar 200 c.c. of nitrogen, prepared as in Experiment 37, and in another jar 50 c.c. of oxygen, keeping mouths of both jars under water. Hold mouth of the one with oxygen under mouth of other, and, tilting former, allow oxygen to enter jar containing nitrogen. Wait until gases have had time to mix (1), (2).

If measuring jar has a spout, transfer the gas to a gas jar as done above. Slip a glass cover under mouth of jar and lift it out of water. Set it upright on bench with cover on.

Plunge into the gas a glowing splinter of wood (3).

Plunge in now a lighted taper (4), (5), (6), (7).

Questions. 1. What is the volume of the mixed gases ?

2. Is there any rise in temperature ?

3. Is the gas oxygen ?

4. Is it nitrogen ?

5. What does it resemble ?
6. Could you have predicted the properties from those of oxygen and nitrogen ?
7. Would you say that air is a compound or a mixture ?

EXPERIMENT 40. *To find the percentage of oxygen in potassium chlorate.*

Method. Find mass of a crucible and lid. Put into it a small quantity of potassium chlorate, say to a depth of about ¼ in. And again find mass. Record your results as under. Put crucible on a pipe-clay triangle on a tripod stand over a small flame. Heat gently till melted. If you heat too rapidly effervescence will cause some of the molten substance to spirt out and be lost. Continue to heat gently until effervescence ceases. You may occasionally lift lid with crucible tongs to see. Now heat more strongly, but carefully. When action seems to be finished, heat as strongly as possible for about ten or fifteen minutes. If there is any solid on underside of lid heat the lid.

Allow crucible to cool, then again find mass. As in Experiment 16, heat, cool, and weigh until mass is constant. Calculate mass of oxygen given off from 100 gm. potassium chlorate.

	Mass of crucible	=	gm.
	,, ,, +potassium chlorate	=	,,
∴	,, potassium chlorate	=	,,
	,, crucible+potassium chloride	=	,,
	,, ,, + ,, ,,	=	,, }
	,, ,, + ,, ,,	=	,, }
∴	,, oxygen driven off	=	,,
∴	gm. potassium chlorate contain		gm. oxygen.
∴	100 gm. ,, ,, ,,	×100	,, ,,
	i.e.		,, ,,
	Class average	=	
	Theoretical percentage, 39·2.		

N.B.—The above method is the usual one of finding the amount and therefore percentage of gas given off when a substance is heated.

SECTION VI

THE PHYSICS OF THE AIR—PRESSURE

PRESSURE

We have defined matter as that which can be moved. Now we have *pushed* open a door; we have *lifted* a piece of coal; we have *kicked* a football; we have seen water *flowing* from the tap; we have seen a magnet *attracting* iron; we have opened a window by *pulling* a rope, and caused a movement in the air which we call a *draught*. In all these examples we have seen bodies in motion, solid, liquid, and gas. In some cases we have exerted a push or a thrust, in others a pull, or an attraction, or a pressure. But in every case we see the result of a *force* of some kind.

If we push against the wall we are still exerting a force or a pressure, though the wall does not move. If nothing else prevented it the wall would move. Thus *force* may be defined as "*that which produces, or tends to produce, motion in a body.*"

If we throw up a stone or a ball into the air it returns to the ground again. It has been moved upwards by a force exerted by the muscles. It is drawn down again by the pull of the earth, or as we say by the *force of gravity*, or, in other words, by its own *weight*, for that is what we mean by the weight of a body. Though the body may be lying on the ground or on the bench, the force of gravity or the weight of the body is still acting, and thus presses on the ground or on the bench, though there is no movement. If we have two forces opposing each other, either there will be movement or there will be no movement. For example, if two men pull a rope between them—say, play tug-of-war—the rope will move towards the one exerting the greater pull or force; but if they pull the same, no matter how much or how little, the rope will not move either way. Or if they push a long pole against each other, the difference of the *pressures* determines in which direction the pole will move—always in the direction of the greater pressure. If they are equal the pole will remain at rest.

We can thus detect a force, whether a pull or a pressure, by the movement it causes in bodies, or by the prevention of motion which would be caused by some known force.

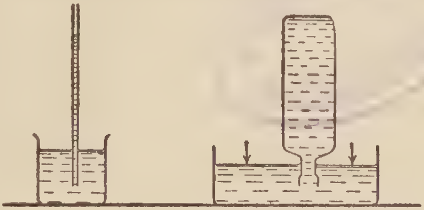
EXPERIMENT 41. *To show that air exerts pressure in all directions.*

Method

A. *Downwards*

I. Dip a piece of glass tubing into water, and suck out some of the air (1), (2).

II. Fill a bottle with water by laying it on its side in a basin of water. Lift it inverted, keeping mouth under water (3), (4).



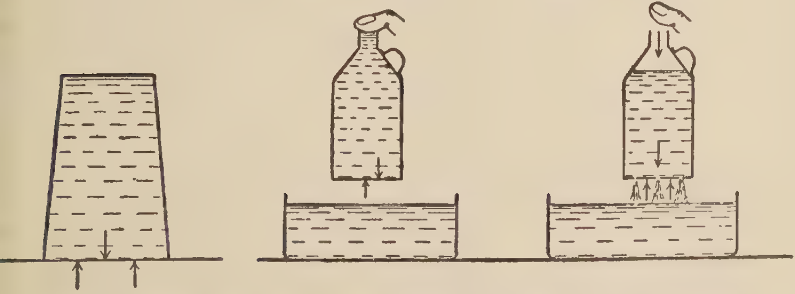
III. Lay a metre stick flat on bench so that it projects over edge. Strike sharply projecting end (5). Now lay over the part of stick on bench a folded-up newspaper, and again strike projecting end of stick (6).

Spread the paper flat over stick on bench, and once more strike sharply as before (7), (8).

IV. Make a boy's "sucker" by cutting a circular piece of leather. Make a hole in centre with a nail, through which pass a piece of strong string and tie a knot on end. Soak in water, and hammer knot as flat as you can. Press wet sucker firmly on a flat stone or sink, and pull string (9), (10). While still pulling, insert a knife under leather (11).

B. *Upwards*

I. Fill a tumbler with water. Place over it a piece of



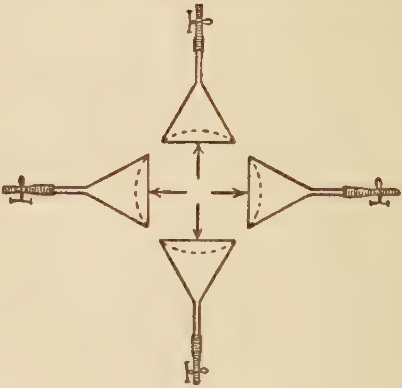
paper. Place the hand over paper to keep it in position. Invert tumbler and take away hand (12), (13).

II. Take a tin flask and put a few holes in bottom. Fill it by pushing it into water in a basin. Putting thumb tightly over mouth, lift it out (14), (15). Lift the thumb (16).

III. Fit a flask with a stopper carrying a thistle funnel and a short tube as in figure. Close short tube with thumb, and pour water into funnel (17).

C. *Equally in all Directions*

I. Wet the sucker and press it against a smooth vertical or sloping wall or bench (18).



II. Stretch a piece of balloon rubber over mouth of a filter funnel. Attach a small piece of rubber tubing with a clip to tube. Suck some air out and close clip while still sucking (19).

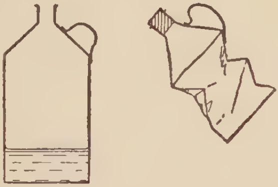
Turn funnel in all directions (20), (21).

Questions. 1. What happens ?
2. What force causes the water to move ?
3. Does the water flow out ?
4. What prevents it ?
5. What happens to the stick ?
6. Is there much more difficulty in raising the stick ?
7. What happens this time ?
8. What prevents the stick and the paper flying up as before ?
9. Is it easy to lift the sucker ?
10. What keeps the sucker sticking to the stone or the sink ?
11. What happens ?
12. Does the water flow out ?
13. What is keeping it in ?
14. Does the water flow out ?
15. What is preventing it ?
16. What happens ? Why ?
17. Can you explain what happens ?
18. What do you infer about the direction in which the air presses ?

19. What happens ? Why ?
20. Is there any difference ?
21. What do you infer ?

Experiment 42. *To show the greatness of the pressure exerted by the air.*

Method. Put a small quantity of water into a tin flask and boil the water. When steam has been issuing for some time, and therefore all the air has been expelled, cork with a tightly fitting rubber stopper, and immediately remove from flame. Cool by pouring cold water over flask.

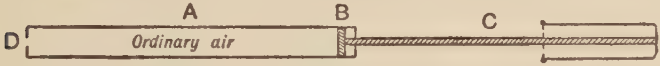


What happens ? Can you explain ?

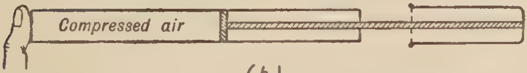
COMPRESSED AIR

Experiment 43. *To find if air can be compressed.*

Method. Examine the construction of a cycle pump. The main parts are (I) the *cylinder* A, the chamber which



(a)



(b)

contains air ; (II) the *piston* B, the oiled disc which slides along the cylinder and fits so closely that no air can pass it ; and (III) the *piston-rod* C, attached to the handle for pushing in the piston. Draw out handle so that piston is in position in fig. (*a*), *i.e.* so that cylinder is full of air. Push in piston (1), (2).

Draw piston back again into first position, so as again to fill cylinder with air. Now close tube D by pressing thumb firmly against it so as to let no air out. Try to push piston down now (3), (4).

Now piston has been pushed down a little, say, into position (*b*), and no air has escaped (5).

While still pushing, remove thumb (6), (7).

With hole open draw up piston a very little, and then close hole with thumb. Now try to pull out piston sharply (8), (9).

Now remove thumb while still pulling (10).

Questions. 1. Is it difficult to do so ?

2. What issues from hole D ?

3. Is it as easy as before ?

4. What is preventing the piston from going so easily ?

5. How does the volume of the air now compare with its volume at first ?

6. What do you notice ?

7. Can you tell anything of the pressure of the air before removing the thumb ?

8. Is it as easy as at first ?

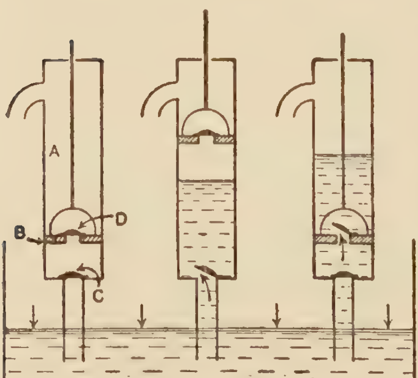
9. How does the volume of air now compare with volume at first ?

10. What happens ?

THE COMMON SUCTION PUMP

Experiment 44. *To study the working of the common pump from a model.*

Method. The diagram represents the common suction or lift pump used in some country districts for getting water from a well. The essential parts of the pump are (I) the *barrel* A, in which slides the *piston* B, and which has a narrower part dipping into the water in the well ; (II) the *valve* C at the top of the narrow tube ; and (III) the *valve* D on the piston.



(a) (b) (c)

In fig. (*a*) we have both valves closed. Draw up piston sharply and watch action of valves (1), (2), (3).

Now push piston down and again observe valves (4), (5).

Continue to raise and lower piston, and observe how water is raised.

Questions. 1. Which valve opens and which remains shut ?
2. What happens to the water-level in the pump ?
3. Why does the water rise ?
4. Which opens and which shuts ?
5. What opens the first ?

Explanation. When the piston is raised from position (*a*), the valve D by its own weight is kept closed, while the air pressing down on the surface of the water in the well forces the water up into the barrel of the pump where the air-pressure has been reduced ; the valve C being forced open by the upward pressure. We have now the condition of things seen in (*b*). If now the piston be pushed down, valve C closes, so that the water above it cannot flow down, while the water displaced by the piston as it comes down pushes the valve D open, and rushes through the valve above the piston as seen in (*c*). On again raising the piston we lift the water which is above the piston, the valve D again closing, and the pressure of the air on the water in the well forcing more water up into the barrel, opening the valve C. The process being continued, the water is gradually forced up, until on reaching the spout E it overflows.

THE "SPRING" OF THE AIR

If we take a piece of rubber we can twist and squeeze it into any shape. But it springs back again into its original shape when we release the pressure. Stretch a bit of rubber cord and let one end go ; it resumes its former length. Compress a metal spring and let go ; it springs back again. This property, possessed by some substances, of being able to return to their former shape or size is called *elasticity* ; and the substances are said to be *elastic*. Such are rubber, glass, ivory. Other substances, like clay, butter, putty, are *inelastic*.

Experiment 45. *To find what happens when air is compressed, and the pressure then released.*

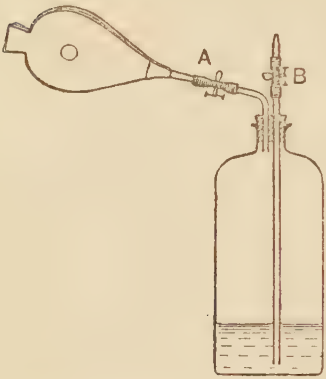
Method. (*a*) Take a rubber ball (one full of air) and press it with the fingers. Press more and more (1).

Release the pressure (2).

(*b*) Take a cycle pump and draw out piston. Close hole

with thumb. Push the piston down sharply (3). Again push down sharply and let go, still keeping the thumb on the hole (4).

Now remove thumb ; push piston down almost to end ; close hole again. Draw out piston sharply and immediately let go (5), (6).



(*c*) Fill a large bottle about half-full of water. Fit it with a tightly fitting, two-holed stopper, carrying a short piece of bent tubing and a long straight piece, the latter reaching nearly to the bottom of the bottle as in the figure. Attach by means of pieces of rubber, A, a pair of bellows ; and B, a short glass tube as a nozzle. Fix clips to A and B. Closing B and opening A, compress the air in the bottle by means of the bellows. Close A, and then open B (7), (8).

Questions. 1. What do you feel the more you press ?
2. Does the ball remain with the dents your fingers made ?
3. What do you feel ?
4. What happens ?
5. Does it remain out ?
6. Can you say anything about the elasticity of the air ?
7. What happens ?
8. What do you infer about compressed air ?

SECTION VII

PHYSICS OF LIQUIDS AND GASES—THE BAROMETER —PRESSURE

MASS AND WEIGHT

We have already defined *mass* as " the amount of matter in a body," and have measured it mostly in grams. We have also seen that the earth is always drawing bodies towards it, and the force with which it does so for each body is called the

weight of the body. And it is common experience that the greater the mass of a body the greater is its weight. But, as we have remarked before, methods employed in our "common experience," as simply lifting, are not accurate enough for our purpose in science. We must have some means of measuring directly the weights of bodies, and, seeing the weight of a body is a *force*, of measuring forces in general, whether they are weights, pressures, pushes, tensions.

EXPERIMENT 46. *To find how a force may be measured directly.*

Method. Take an elastic cord or spiral spring fixed to a piece of wood, so that it hangs freely in a groove in the wood. Attach by strings a pan suitable for carrying a number of small "weights." (An ungraduated Watson's spring balance will do.) Gum a strip of squared paper, reading cm. and mm., on the wood alongside of spring. Fix wood in a clamp, so that spring hangs vertically.

Stretch spring a little and let go to see that it is not prevented from stretching freely.

Fix an ordinary pin at bottom of spring to act as a pointer on the squared paper. Mark its position 0 on paper.

Now add a mass of 10 gm. (1). Mark carefully on paper position indicated by pointer. Add another 10 gm. and repeat. Continue adding 10 gm. at a time until total mass in pan is 100 gm., marking positions each time on paper (2). Remove masses (3).

Measure unstretched length of spring (*i.e.* the distance from point of suspension to the position of the pointer when there is no mass on the pan), and the lengths corresponding to masses added. Complete table as under (4).

Stretching weight.	Original length.	Final length.	Extension.	$\dfrac{\text{Extension.}}{\text{Stretching weight.}}$
0 gm.	cm.	cm.	cm.	
10 ,,	,,	,,	,,	
20 ,,	,,	,,	,,	
..	..	..	..	
100 ,,	,,	,,	,,	

Questions. 1. What is stretching the spring ?

2. How does the amount of stretching of the spring vary with the mass in the pan ?

3. Does the pointer resume its original position ?

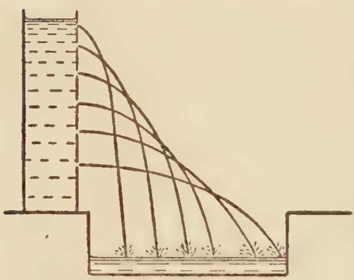
4. What is the relation between the extension (*i.e.* the amount of stretching) and the stretching force ?

PRESSURE OF LIQUIDS AND GASES

We have already found that gases exert pressure because of their weight ; we are now going to study whether liquids also exert pressure. We shall also find the reasons why water can reach the tops of high buildings without apparently being forced up ; why the spout of a teapot should reach as high as the lid ; how a fountain works ; why an iron ship floats ; why a balloon rises ; and the reasons for other everyday occurrences.

EXPERIMENT 47. *To find whether a liquid exerts pressure.*

Method. (*a*) Take a tall cylindrical tin. (Those sold with calcium carbide are very suitable.) Punch four or five holes with a nail in a vertical line down the side. Keeping holes closed, fill tin with water, and then open holes (1), (2), (3), (4). The experiment may be made continuous by allowing water to flow from tap into cylinder. Stop flow into can (5).



Questions. 1. What happens ?

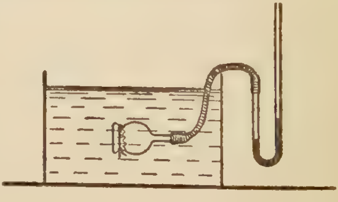
2. What forces the water out ?

3. From which hole is the water forced out with (*a*) least (*b*) greatest pressure ?

4. How does the pressure depend on depth ?

5. What happens to the jets of water as the level falls ?

(*b*) Take a thistle funnel with a short tube. Stretch a piece of balloon rubber across the mouth and tie it on firmly. By means of a long piece of rubber tubing connect it to a U-tube con-



taining a quantity of water, coloured, say, with ink. Fix U-tube vertically. Press rubber film gently (1), (2). Press further (3).

Release pressure (4), (5).

Now push rubber film gradually into a basin of water (6).

Raise thistle funnel gradually up through water, and out of it, and tell what happens (7).

Questions. 1. What are you doing to the air inside ?

2. What happens to the liquid in the U-tube ?

3. Is there any change ?

4. Does the liquid go back ?

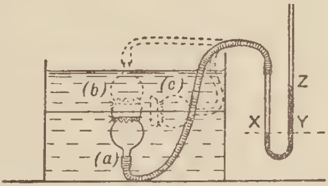
5. Can you use the U-tube as a gauge of the pressure on the rubber ?

6. As the film goes deeper, what about the movement in the U-tube ?

7. What do you infer about the pressure the deeper you go down ?

EXPERIMENT 48. *To show that the pressure at a certain depth in a liquid is the same in all directions.*

Method. Using same apparatus as in last experiment, lower funnel into water to a convenient depth in position (*a*), so that rubber film is horizontal and pressure of the liquid on it is downwards. Mark by means of gummed paper level of liquid in either limb of U-tube. Now invert thistle funnel into position (*b*), keeping rubber film horizontal, and at same depth as in position (*a*) (1), (2), (3).



Again place funnel in position (*c*), so that rubber film is vertical, with its centre at same depth as before, *i.e.* so that average depth is same as in (*a*) and (*b*) (4).

Repeat with diaphragm in any position, but keeping its centre at same depth (5).

Questions. 1. In what direction is the liquid now pressing on the diaphragm ?

2. Is there any movement of the liquid from position in (*a*) in the U-tube ?

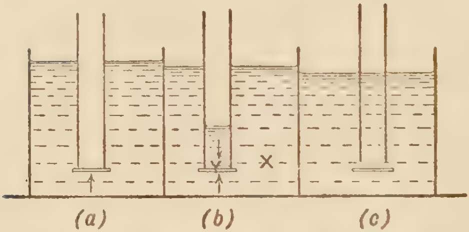
3. Is there any difference between the upward and the downward pressures at the same level ?

4. Is there any change in the pressure ?

5. What do you infer about the pressure of a liquid in various directions at a certain depth ?

EXPERIMENT 49. *To find how we can measure the pressure at a certain depth in a liquid.*

Method. Take a glass disc ; hold it horizontally into a basin of water, and let go (1).



Take a glass cylinder open at both ends (a wide glass tube will do) whose diameter is less than that of disc, one which does not fit tightly on the plane of the disc, but leaves a little space between them. Hold disc against bottom of cylinder (which is held vertical), and then let go (2).

Again hold it on and plunge it vertically into a deep trough of water, with disc downwards, and then let go disc (3), (4) (fig. *a*), (5).

Watch water rising in cylinder (6), (7), (8), (9).

Questions. 1. What makes it sink ?
2. Does it remain against the cylinder ?
3. Does the disc now fall away ?
4. What prevents it from falling ?
5. At the same time is there any water entering the cylinder ?
6. When does it stop rising ?
7. What happens when the level of the water inside reaches the level outside the cylinder ?
8. What forces are acting on the disc when it falls away ?
9. What do you infer about the magnitude of the pressure at the foot of the cylinder ?

THE BAROMETER

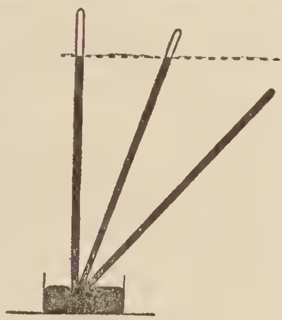
EXPERIMENT 50. *To measure the pressure exerted by the air.*

Let us refer again to the diagram of Experiment 48. Note the position of the liquid in the U-tube. Here we have it at two different levels ; in other words we have a " head of

liquid," and the liquid is still at rest. We must therefore have equal pressures at the same levels, *i.e.* pressure at X must equal pressure at Y. But the pressure at X is the pressure of the air in that limb, and the pressure at Y is the pressure of the air at Z plus the pressure of the head of liquid YZ. We have thus a pressure of gas being balanced by a head of liquid. If we can measure this head of liquid then we have a means of measuring the pressure of a gas. This is what we do in measuring the pressure of the air, or atmospheric pressure, as it is called. We cause this pressure to balance a head of a liquid which we can conveniently measure.

N.B.—This experiment should be performed over a mercury tray to catch any mercury which may be spilt. A large sheet of paper with turned-up edges is suitable.

Method. (*a*) Put clean, dry mercury into a small basin. Take a clean, dry, thick-walled glass tube about a yard long, closed at one end, and fill it to within an inch of top with more mercury. (This is done by attaching a short thistle funnel by means of rubber tubing.) Place thumb over open end and invert, so that a bubble of air goes right along tube and collects any small bubbles that may cling to tube. Re-invert and completely fill tube with mercury. With thumb over open end, invert it carefully with this end under surface of mercury in basin, and remove thumb. Clamp tube vertically (1), (2), (3), (4), (5), (6), (7), (8).



Measure head of mercury in inches and in centimetres. This apparatus is called a *simple barometer*. Clamp a metre stick horizontally at height of the mercury in tube, and tilt tube gently, keeping open end under surface of mercury in basin (9). Continue to tilt tube until top comes under metre stick. Do it sharply (10), (11).

(*b*) Calculate the pressure of the air in grams per sq. cm. as under.

Length of head of mercury	=76 cm. (say).
Suppose area of cross-section of tube be	a sq. cm.
Then volume of mercury column	=76a c.c.
But 1 c.c. of mercury weighs 13·6 gm.	

∴ weight of mercury column	$=76a \times 13{\cdot}6$ gm.
∴ pressure on a sq. cm.	$=1033{\cdot}6a$ gm.
∴ pressure on 1 sq. cm.	$=1033{\cdot}6$ gm.
∴ atmospheric pressure	$=1033{\cdot}6$ gm. per sq. cm.

Note that this number does not involve a, the cross-sectional area (12).

Also calculate the pressure in lb. per sq. in.

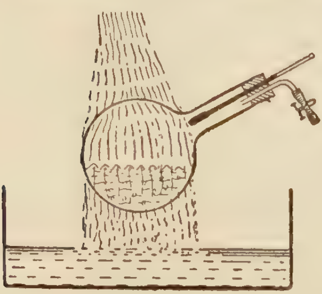
(*c*) Take readings of the height of the barometer for a few days in succession (13).

Questions. 1. What happens ?

2. Why did the mercury move ?
3. Why did it stop falling ?
4. What is keeping it from falling further ?
5. What is in the space above the mercury in the tube ?
6. What is pressing on the surface of the mercury in the basin ?
7. Where else is the pressure atmospheric ?
8. What then measures the atmospheric pressure ?
9. What do you notice about the top of the mercury column ?
10. Do you detect any sound as the mercury touches the top of the tube ?
11. What precaution must be taken to read correctly the height of the barometer ?
12. Would it make any difference to the height of the barometer if the tube were wider or narrower ?
13. Does it remain at the same height ?

EXPERIMENT 51. *To find the effect of* (a) *increase,* (b) *decrease of pressure on the boiling point of a liquid.*

Method. (*a*) Put some water into a round-bottomed flask. Fit it with a two-holed stopper carrying a thermometer and a short piece of glass tubing bent at right angles, to which is fastened a short piece of rubber tubing. Boil the water and note boiling point while steam is issuing freely from rubber tubing. With the fingers carefully but firmly close rubber tubing *for a moment*, watching thermometer carefully (1), (2), (3), (4).



(*b*) Now extinguish flame, and immediately close rubber tubing by means of a clip. Remove flask to sink (5), (6).

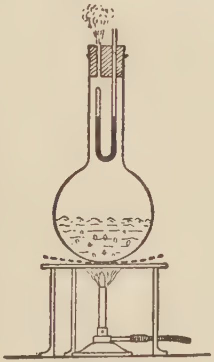
Allow a little cold water to fall on flask (7).
Read temperature.
Continue pouring cold water over flask for some time, and read temperature just when it ceases to boil (8), (9).
Observe shape of rubber tube next clip (10).
Gradually open clip (11), (12).

Questions. 1. What is the temperature now ?
2. What do you observe about the issuing steam when you take away the fingers ?
3. What about the pressure inside the flask when the steam was prevented from coming out ?
4. What do you infer about the effect of increase of pressure on the B.P. of a liquid ?
5. Is the water still boiling ?
6. What is above the water in the flask ?
7. What happens ?
8. What does the cold water do to the steam inside ?
9. What then happens to the pressure inside ?
10. Can you explain the flatness ?
11. What do you hear ?
12. What do you infer about the effect of decrease of pressure on the B.P. ?

EXPERIMENT 52. *To show that the pressure of steam from boiling water is equal to the pressure of the atmosphere.*

Method. Take a piece of glass tubing about 10 in. long; close it at one end and bend it (in a fish-tail burner) to shape as shown in fig. (*a*). Fill it with mercury to within $\frac{3}{4}$ in. of open end, and fill remaining portion with water. Close it with thumb, and by inverting get water round bend into closed end, the rest being filled with mercury. By cautious handling, jerk mercury out of tube until the level in open limb is lower than the level of mercury in closed limb as shown in fig. (*a*). Fix tube in one of the holes of a two-holed stopper, leaving other open. Fix stopper in a flask of water in position (*b*). Heat the water (1).


(*a*)


(*b*)

Boil the water and keep boiling for a time (2), (3), (4), (5), (6).

Questions. 1. What do you observe about the water in the tube ?

2. What has happened to the water in the tube now ?
3. What do you observe about the levels of mercury ?
4. What is the pressure on the mercury in the open limb ?
5. What is pressing on the mercury in the closed limb ?
6. What do you infer about the pressure of the steam when water is boiling ?

SECTION VIII

PHYSICS OF LIQUIDS—PRINCIPLE OF ARCHIMEDES—FLOTATION

EXPERIMENT 53. *To compare the weight of a body in air with its weight in water.*

Method. (*a*) Tie a string round a large body, say, a brick, and hang it on the hook of a spring balance. Note weight of brick. Lower brick a little into a pail or tank of water (1). Lower a little further (2). Continue to lower brick until completely immersed. Note the reading (3), (4).

Now gradually raise brick out of water. Repeat with a brick of same size but different material and therefore different weight (5).

Questions. 1. What do you observe on the balance ?

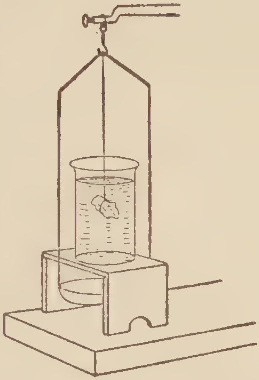
2. What does the body appear to weigh now ?
3. Has any of the *mass* of the brick been lost ?
4. Why then does it seem to lose weight ?
5. On what does the apparent loss of weight depend ?

(*b*) We have seen from Experiment 46 that the weight of a body is proportional to its mass, *i.e.* a body having twice the mass of another body has twice its weight. We can therefore use the beam balance to compare, and hence to measure weights.

Weigh a stone or other suitable object (*e.g.* a glass stopper), by hanging it from the stirrup of the balance by means of thread. Place stool across pan of balance, so that it can swing freely without touching when the beam is raised. Place

a beaker of water on stool so that the stone is hanging totally immersed in water when balance swings.

N.B.—Use as little thread as possible, as it absorbs water and it also has weight. Now find apparent weight of stone thus immersed. Find upthrust of the water on stone.



Take out stone, dry it, and find volume and thence weight of water it displaces, by means of a measuring jar. Arrange your results as below. Note the results obtained by other members of class.

Question. What relation do you find between the upthrust and the weight of water displaced ?

Repeat the experiment with a liquid whose density has already been found.

	Weight of body in air	=	gm.
	,, ,, water	=	,,
∴	upthrust	=	,,
	First reading of measuring jar	=	c.c.
	Second ,, ,, ,,	=	,,
∴	volume of water displaced	=	,,
∴	weight ,, ,, ,,	=	gm.

ABSOLUTE AND RELATIVE DENSITY

The Principle of Archimedes, though a very important fact in itself, helps us to find very accurately the volumes of bodies. By weighing the body in air and then in water we have the upthrust of the water on the body, which gives us the weight of water displaced by the body, and thus the volume. And knowing the mass and the volume we can calculate the density.

We have already defined the density of a body as " the mass of unit volume " of the body ; but more often we employ the term " relative density " or " specific gravity." By either of these phrases we mean *the number of times the body is as dense as water*. Hence relative density is measured by the ratio $\dfrac{\text{weight of the body}}{\text{weight of the same volume of water}}$.

It is evident, therefore, that if a body have a density of 11·4 gm. per c.c. its relative density is 11·4.

EXPERIMENT 54. *To find* (1) *the volume,* (2) *the density,* (3) *the relative density of a solid by the Principle of Archimedes.*

Method. Proceed as in last experiment, and record as under.

	Weight of solid in air	=20 gm.
	,, ,, ,, water	=18 ,,
∴	upthrust	= 2 ,,
∴	by P. of A. weight of water displaced	= 2 ,,
∴	volume of water displaced	= 2 c.c.
and ∴	(1) volume of solid	= 2 ,,

$$\therefore (2) \text{ density of solid} = \frac{\text{mass of solid}}{\text{volume of solid}} = \frac{20 \text{ gm.}}{2 \text{ c.c.}}$$
$$= 10 \text{ gm. per c.c}$$

and

$$(3) \text{ relative density of solid} = \frac{\text{weight of solid}}{\text{weight of equal volume of water}}$$
$$= \frac{\text{weight of solid}}{\text{weight of water displaced}} = \frac{20 \text{ gm.}}{2 \text{ gm.}} = 10.$$

EXPERIMENT 55. *To find the density of a liquid by the Principle of Archimedes.*

Method. As before, weigh a suitable solid (*e.g.* a glass stopper) first in air and then in water, and finally in the liquid whose density is to be found. Find, as before, weight of water and of liquid displaced. From former we find volume of water displaced, which is volume of solid, and also volume of liquid displaced. Enter as under :—

	Weight of solid in air	=	gm.
	,, ,, ,, water	=	,,
	,, ,, ,, liquid	=	,,
∴	,, ,, water displaced	=	,,
∴	volume ,, ,, ,,	=	c.c.
∴	,, ,, solid	=	,,
and ∴	,, ,, liquid displaced	=	,,
	But weight of liquid displaced by P. of A.	=	gm.

$$\therefore \text{density of liquid} = \frac{\text{mass of liquid displaced}}{\text{volume of liquid displaced}} = \frac{\quad \text{gm.}}{\quad \text{c.c.}}$$
$$= \quad \text{gm. per c.c.}$$

$$\text{And relative density of liquid} = \frac{\text{weight of liquid displaced}}{\text{weight of water displaced}}$$

$$= \frac{\quad \text{gm.}}{\quad \text{gm.}} = \qquad .$$

EXPERIMENT 56. *To find if the Principle of Archimedes holds good in the case of a floating body.*

Method. (*a*) Hang a large block of wood by means of a string to the hook of a spring balance. Read the weight. Gradually lower it into a pail of water and note what happens to the pointer.

Question. What does it weigh while floating ?

(*b*) For this experiment a large uncut pencil, or a candle, is a suitable body.

Find weight of body on balance. Pour into a measuring jar a suitable quantity of water; take reading. Float body vertically in the water, seeing that it floats freely. Take new reading.

Repeat with methylated spirit and salt solution instead of water, or other suitable liquids in which body will float and whose densities have been found. Complete the following table :—

Weight of floating body= gm.

Liquid.	Measuring jar readings.		Volume of liquid displaced.	Density of liquid.	Weight of liquid displaced.
	First.	Second.			
				gm. per c.c.	
Water	c.c.	c.c.	c.c.	1·00	
Meth. spirit	,,	,,	,,	0·82	
Salt solution	,,	,,	,,		

Question. How does the weight of a floating body compare with the weights of liquids displaced ?

EXPERIMENT 57. *To float a solid body in* (1) *water,* (2) *another liquid, and deduce the density of* (a) *the solid body, and* (b) *the second liquid.*

An uncut pencil (or a candle) is a suitable solid.

Method. Take a measuring cylinder, pour into it some water, and take reading. Now float solid upright in water and again take reading (1).

By means of a pen push solid down till it is just totally immersed, and take a third reading (2). Calculate density of solid.

Repeat with second liquid (3). Record as under.

With water—

First reading of measuring jar = c.c.
Second ,, ,, ,, = ,,
Third ,, ,, ,, = ,,
∴ volume of water displaced by floating solid = ,,
∴ weight ,, ,, ,, ,, = gm.
∴ by Law of Flotation, weight of solid = ,,
Also volume of solid = c.c.

$$\therefore \text{ density of solid} = \frac{\text{gm.}}{\text{c.c.}} = \quad \text{gm. per c.c.}$$

With second liquid—

First reading of measuring jar = c.c.
Second ,, ,, ,, = ,,
∴ volume of liquid displaced by floating solid = ,,

But, by Law of Flotation, weight of liquid displaced
= weight of floating body
= gm.

$$\therefore \text{ density of liquid} = \frac{\text{weight of liquid displaced}}{\text{volume of liquid displaced}}$$

$$= \frac{\text{gm.}}{\text{c.c.}} = \quad \text{gm. per c.c.}$$

Questions. 1. Can you deduce the weight of the candle ?

2. Can you tell the volume of the candle ?

3. What is the (*a*) volume, (*b*) weight, (*c*) density of liquid displaced ?

SECTION IX

MAGNETISM

EXPERIMENT 58. *To examine some of the properties of a magnet.*

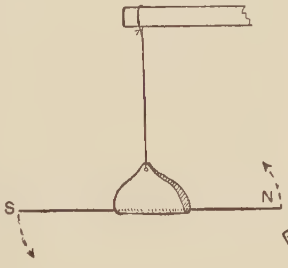
N.B.—Do not drop or hammer the magnets, or you will destroy the magnetism.

Method. *A*. Go round the room with a magnet and test various substances, making a note of those it attracts and those it does not.

B. Dip magnet into iron filings and lift it out. Describe what you see (1), (2).

Dip an unmagnetised needle into filings (3).

C. Suspend a magnet by means of a paper stirrup and a thread (as in the diagram) from a wooden stand, so that it is free to swing horizontally. Or set it on a large cork floating in water. (Or set up a small magnetic needle swinging on a pivot made by fixing a sewing needle into a cork.) Allow to swing and describe its motion. When it comes to rest note its direction by looking along it and marking a point on the wall of the room towards which it points. Set gently swinging again, and when it comes to rest note direction once more (4).



From the position of the sun and the time you can tell approximately the directions (5).

Mark end of magnet towards North (6).

Repeat with an unmagnetised needle (7).

D. Bring marked end of another magnet near marked end of swinging magnet (8).

Bring two other ends of the magnets near each other (9).

Now bring a marked end near an unmarked end, and *vice versa* (10).

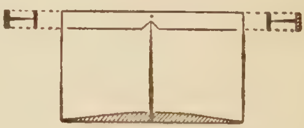
Bring near each end of the swinging magnet each end in turn of an unmagnetised needle (11).

Suspend now the unmagnetised needle, and bring near it first one end and then the other of a magnet (12), (13).

Questions. 1. Do the filings cling to all parts of the magnet ?
2. Where does the strength of the magnet seem greatest ?
3. Do the filings cling to it ?
4. What do you infer about the position of rest ?
5. In what direction does the magnet come to rest ?
6. Is there anything to distinguish it from the other ?
7. Does it behave in the same way ?
8. What happens ?
9. What happens ?
10. Is there any difference ?
11. Is there any movement ? If so, what is it ?
12. Does it behave in the same way ?
13. How could you tell if a piece of steel is a magnet ?

THE MARINER'S COMPASS

From our last experiment on the properties of a magnet, it will be evident how useful the magnet will be to sailors in finding directions on the ocean where there are no fixed marks to guide them. The sailor's needle, or, as it is called, the *Mariner's Compass*, is so constructed that it always remains horizontal, which is very necessary, because of the difficulty of reading an ordinary magnet needle on account of the pitching of the boat.



It consists of three parts—the Box, the Card, and the Needle.

The *needle* is composed of several pieces of steel magnetised, and these are fixed to a circular sheet of a non-magnetic substance called mica. To this is fastened the *card* containing the points of the compass accurately marked. This mica disc is balanced by being delicately pivoted on an upright pointed pin fixed in the bottom of the *box*, so that the card, hanging on the pin, turns freely round its *centre*, and one of the points on the card will always be pointed towards the North. To ensure, however, that the card will always remain horizontal, no matter how much pitching the boat is subjected to, the box is hung within a wooden case by two

concentric brass rings or gimbals. First the box swings about two pins at opposite ends of a diameter, fixed to the inner gimbal, as at (*a*) and (*b*) in the plan given. Then the inner gimbal swings about two pins at opposite ends of a diameter at right angles, fixed to the wooden case, as at (*c*) and (*d*).

Certain devices are employed to ensure that the needle acts truly even on iron ships, and the compass accurately tested before the ships sail.

The direction in which the ship is sailing is got by simply looking at the needle, allowance always being made for declination in the construction.

The four *principal points of the compass*, called the *cardinal points*, are North, South, East, and West, the names of the others being compounded of these.

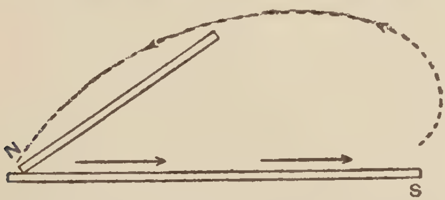
METHODS OF MAGNETISING

EXPERIMENT 59. *To magnetise a piece of steel.*

Method. I. *Single Touch.*—Test a steel knitting needle or piece of clock spring for magnetism. If it is magnetised heat strongly in a flame and allow to cool. Test again (1).

Find mass of the needle.

Now lay it on bench and hold it with one hand. With pole

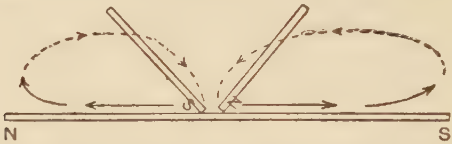


of a bar magnet stroke from one end to other of the needle, keeping magnet sloped as in the figure. Lift the magnet, and repeat operation about a dozen times. (*N.B.*—Do not rub backwards.) Note which pole of magnet you use to stroke needle. Test for magnetism (2). Observe polarity of needle (*i.e.* which end is N. and which S.) (3).

Again find mass of the needle (4), (5).

II. *Separate or Divided Touch.*—Fix an unmagnetised knitting needle or clock spring on the bench by means of wax or copper tacks. Take two magnets—one in each hand.

Bring unlike poles together at centre of needle, but not touching each other. Sloping them as in figure, draw them



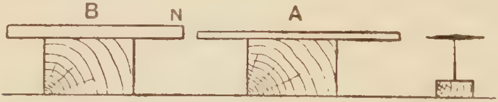
apart towards ends of needle. Lift them from needle, and repeat stroking about a dozen times. Test needle for magnetism. Observe poles and also poles of the magnets used (6).

Questions. 1. Is it still magnetised ?
2. Is the needle magnetised ?
3. What connection do you find between the pole of the magnet used and the pole of the needle last touched ?
4. Is there any change in mass ?
5. What kind of change has the steel undergone ?
6. What connection do you find between them ?

MAGNETIC INDUCTION

EXPERIMENT 60.—*To find what happens to iron when in presence of a magnet.*

Method. I. Arrange a piece of soft iron (A) and a permanent magnet (B) as in figure, the N-pole of the magnet being next



the iron ; take care that they do not touch ; rest each on a block of wood. Test iron for magnetism (1), (2). Remove the permanent magnet (3).

Replace magnet, but have it reversed, so that the S-pole is next iron. Test polarity again (4).

II. Arrange a second piece of soft iron (C) behind first piece. Test it for magnetism. Repeat experiment as in Part I.

III. Clamp a magnet vertically from a wooden clamp, and hang a nail (or pen-point) from it by attraction. See if another pen-point can cling to the first, and then a third, and so on. Test if last one is magnetised.

Can you now tell how a permanent magnet attracts iron ?

IV. Hold a rod of iron (a poker will do) in magnetic meridian with the N. end pointing downwards at an angle to horizontal. Knock it several times with a piece of wood or with the knuckles, and then test if it is magnetised (5).

Now hold it E. and W., and knock as before : test again for magnetism (6).

Questions. 1. Is it magnetised ?

2. What is the polarity of the end next the magnet ?

3. Is the iron still magnetised as much as when the magnet was present ?

4. Any connection between the poles of the magnet and those of the iron ?

5. What do you find ?

6. Is it magnetised ?

PART II—THEORETICAL

SECTION I

VOLUME—MASS—DENSITY

Experiment 1. It is obvious from this experiment that when the solid is lowered into the water the water level rises, not because more water has been poured in, but because some of the water was pushed out of the way to make room for the solid. It is also obvious that the further the solid sank into the water, the more water was *displaced*, until all the solid was immersed. Hence the volume of the solid was equal to the volume of the water displaced, and this was measured by the rise in the jar. Two bodies cannot occupy the same space at the same time. This method of finding the volume of bodies is known as the *method by displacement.*

Historical. The above method is due to an ancient Greek called Archimedes, who lived in the third century B.C. in Syracuse, Sicily. The tyrant of Syracuse at that time, Hiero by name, had received a gift of gold, which he handed over to a goldsmith to make into a crown. On the crown being returned, Hiero suspected that some of the gold had been retained by the goldsmith, and an equal quantity of some base metal had been added. Sending for Archimedes, who had a reputation as a wise man, he acquainted him of his suspicion and asked if he could tell whether the crown was pure gold or not. The philosopher, continually thinking of a method of finding the volume of the crown, one day while taking a bath had filled the bath full. Getting in, he observed that the water overflowed, and the fact suddenly dawned on him that the volume of water that had overflowed, *i.e.* was displaced, was equal to the volume of his body. Hence a method of finding the volume of the crown, and also of finding the volume of a piece of pure gold having the same weight: for the volume

of the crown should be the same as the volume of the gold that Hiero had given to the goldsmith if it were all there.

EXPERIMENT 3. It is no mere coincidence that the mass of 1 c.c. of water is 1 gram.: it was made so. You will now understand how the gram is derived. *A gram is the mass of 1 cubic centimetre of pure water at* 4° *C*. (You will learn later what 4° C. means, and why that temperature was taken.)

Historical. During the time of the French Revolution, towards the end of the eighteenth century, the Revolutionary Government resolved to introduce a new system of measurements, and in order that it might be permanent they took the distance from the North Pole to the Equator measured along the meridian through Paris, divided it into 10,000,000 equal parts, and called each part *one metre*. Hence the name the *Metric System*. (The standard metre is the distance between two very fine lines ruled on a bar of platinum-iridium kept at the International Bureau of Weights and Measures at Sèvres, near Paris.) This unit, though not exactly what it was meant to be, is a little more than a yard. It was further divided into 100 equal parts, called *centimetres* (Latin: *centum* =100). A centimetre is about the breadth of your finger-nail.

EXPERIMENT 4. You have now found that the mass of 1 c.c. of turpentine is less, and the mass of 1 c.c. of mercury is very much more, than the mass of 1 c.c. of water. In science we say that turpentine is less *dense*, and mercury denser than water. This is what we really mean when we say that turpentine is "lighter," and mercury "heavier," than water.

By the *density* of a substance we mean the *mass of unit volume*. In the Metric System the density of water is 1 gm. per c.c.; of mercury 13·6 gm. per c.c. Using British units we could say that the density of water is 62·5 lb. per cu. ft., and that of mercury $62{\cdot}5 \times 13{\cdot}6$, *i.e.* 850 lb. per cu. ft.

If water, turpentine, and mercury be shaken up together in the same vessel and allowed to stand they gradually separate again, the mercury falling to the bottom and the turpentine rising to the top. We infer, therefore, that if liquids of different densities be put into the same vessel, the densest falls to the bottom and the least dense rises to the top.

It is important to note that in mercury the meniscus is curved the opposite way to the meniscus of water. This is the case with those liquids, like oils, which do not wet the sides of the vessel. The *top* of the curve is in these cases read.

Experiment 6. The fact that the mass of 1 c.c. of water is 1 gm. affords an accurate method of finding the capacity of a vessel. The number of grams in the mass of water it contains equals the number of cubic centimetres in its capacity. The capacity of a large vessel is measured in litres. *A litre is* 1000 *c.c.* and is equivalent, in British measure, to 1·76 pints ($1\frac{3}{4}$ approx.).

A list of densities of the more common substances is here given in grams per cubic centimetre :—

Solids.		*Liquids.*	
Aluminium	2·58	Water	1·00
Copper	9·0	Alcohol	·79
Cork	·24	Glycerine	1·26
Glass	2·6	Mercury	13·6
Gold	19·3	Turpentine	·87
Iron	7·4		
Lead	11·4		
Silver	10·5		

SECTION II

HEAT—EXPANSION—THERMOMETRY

Experiment 7. (*a*) The rod of metal before being heated fits into the gauge without difficulty. When heated, however, it does not go into the gauge XY. We infer therefore that the rod is longer than when it was cold. Hence heating the rod has increased its length. But it fails also to go into the hole: hence its breadth has also increased. In fact it has expanded in all directions. On allowing the rod to cool and again testing, it is found that the rod fits both gauges. Hence the metal has contracted when cooled. Of course the gauge itself has expanded by being heated by the rod, but if both be allowed to cool, the rod fits again into the gauge.

(*b*) The compound rod of iron and copper when heated is found to curve, with the copper on the outside of the curve, showing that the copper is longer than the iron. The two metals have, therefore, expanded unequally, and the copper

more than the iron, when equally heated. If the rod be allowed to cool to its former state, it becomes straight again. (If the rod be immersed in ice so as to cool it further it would be found to curve this time with the copper on the inside, showing the copper was shorter than the iron and had therefore contracted more.) We conclude that—

(1) Solids expand when heated and contract when cooled.
(2) Different solids expand unequally when equally heated.
(3) Copper expands more than iron.

Experiment 8. When the flasks are plunged into the hot water, the liquids momentarily fall in the tubes. The reason is that the glass gets the heat first and so expands, thus increasing the capacity of the flask before the heat reaches the liquid inside ; hence some of the liquid falls down to take the place of the expansion. When, however, the liquid is heated it rises up the tube, thus showing it has expanded. It rises higher than its original level, which shows that the liquid expands more than the glass, a solid. Besides, the liquids rise to different levels, the methylated spirit rising higher than the water, illustrating the different expansions. When removed from the hot water and allowed to cool, the liquids fall, showing that when cooled liquids also contract. Hence

(1) Liquids expand when heated and contract when cooled.
(2) Liquids expand more than solids when equally heated.
(3) Different liquids expand unequally when equally heated.
(4) Methylated spirit expands more than water.

Experiment 9. If a so-called "empty" bottle (or any vessel) be pushed mouth downward into water, the water does not fill the bottle, because it is not really empty : it is full of air. If the bottle be turned upright, bubbles come out and rise through the water : they are bubbles of air being displaced by the water entering the bottle. We infer then that air is made of matter—it can be moved. We can smell coal gas, though we cannot smell air. Coal gas is therefore also composed of matter. When these bottles or flasks, filled as in this experiment with these gases, are plunged into warm water, the coloured water, which acts as an indicator, rises in the tubes, showing that gases expand when heated. It is also evident by comparison with Experiment 8 that gases expand quicker than liquids—that is, they expand more than liquids if heated to the same extent. The water rises in each tube

to the same height, showing that air and coal gas, unlike water and methylated spirit, expand equally. This is the chief difference between gases and liquids as regards expansion. On removing the flasks from the water and allowing them to cool, the liquid falls in each tube, showing that gases contract when cooled. (*N.B.*—The gases in the flasks have the same volume to begin with, and the tubes have same bore.) Hence

(1) Gases expand when heated and contract when cooled.
(2) Gases expand more than liquids and solids when equally heated.
(3) All gases expand equally when equally heated.

Experiment 10. The "red-hot" pin was obviously much hotter than the lump of metal; and when brought into contact with the latter it immediately became colder. Heat had passed from the pin to the colder metal. We say then, in scientific language, that the pin was *at a higher temperature* than the metal. *Temperature may be defined as "degree of hotness"; it is that condition of a body which determines whether heat will pass from it or to it when placed in contact with, or near to, other bodies.*

But what is *heat*? The temperature of the water into which the pin was plunged was not appreciably raised, but that which received the larger body was distinctly hotter. Thus, although the small body was at a much higher temperature, the colder body gave out much more *heat*. Now the mass of a body when cold is the same as when hot. Hence heat is not composed of matter. *Heat is simply the rapid movement of the particles composing the body.* The particles cannot be seen in the most powerful microscope, nor can their vibration. But from the results of very fine experiments we are led to understand that the more rapid the vibration of the particles, the higher is the temperature. Hence if a hot body, say, comes in contact with or is placed near a colder body, the rapid movement of its particles is transferred to the particles of the colder, and hence the temperature of the latter is raised; and since the movement of the particles of the hotter body is consequently diminished, its temperature is lowered. Thus heat passes until the temperatures are the same.

Hence, when we "heat ourselves" before the fire, heat passes to us from the fire; and when we "feel cold," heat is passing from us to bodies at a lower temperature.

When the temperature, therefore, of solids, liquids, and gases rise, their volumes increase.

N.B.—It will be obvious that we cannot talk of "large" or "small" temperatures, but "high" and "low" temperatures; and temperatures "rise" or "fall," but do not "increase" or "decrease."

EXPERIMENT 11. At first the two thermometers register the temperature of the air in the room. On plunging them into the ice, their temperatures are lowered, as shown by the contraction, and therefore the fall of mercury. This fall continues, at first rapidly, then gradually more slowly until the mercury attains the temperature of the ice. When steady, the levels read 0° on the Centigrade scale and 32° on the Fahrenheit. Now the temperature of the air is above that of the ice; heat must therefore be passing from the air to the ice, and still the temperature of the ice is not rising. The reason is that the heat is going to *melt* the ice, *i.e. change its state from solid to liquid.* If heat be supplied slowly to the ice, with constant stirring, it melts; but *the temperature does not rise until all the ice is melted.*

This constant temperature at which a solid melts is called its *melting point* (contracted to M.P.). The heat which goes to change a solid into its liquid at the melting point is called *latent heat of fusion*; in this case latent heat of fusion of ice, or simply *the latent heat of ice* (Latin: *lateo*=I lie hid). We shall find later that water *freezes*, *i.e.* changes into the solid state, at the same temperature, 0° C. or 32° F.; so that we sometimes use the term F.P. (*freezing point*) instead of M.P.

EXPERIMENT 12. As the water is heated the temperature rises. Before it boils small bubbles appear on the inside of the flask, collecting on the sides. This is air which has been *dissolved* in the water, and the heat expands the small particles of air into bubbles. When it is boiling, the mercury remains stationary at about 100° C. or 212° F., and does not rise any higher *as long as the boiling is continued*; i.e. *as long as there is any water left.* The heat that is being supplied is going to change the water into steam or water vapour. (Notice that the steam is the clear, colourless gas above the water in the flask; it is not the white cloud seen outside the flask; that is composed of small particles of water formed by the steam condensing in coming into the cold air.)

This constant temperature at which a liquid boils is called

its *boiling point* (contracted to B.P.). The heat that goes to change a liquid into its *vapour* is called *latent heat of vaporisation*; here latent heat of vaporisation of water, or simply *latent heat of steam.* (Note that the term "steam" is used only for the vapour of water; you cannot call the vapour coming from, say, boiling alcohol, steam, but *alcohol vapour.*)

EXPERIMENT 13. The boiling point of alcohol is found to be 78° C. Its freezing point is −130° C., *i.e.* 130 degrees below the temperature of melting ice.

RANGE OF THERMOMETERS

It will be evident that the complete range of temperatures through which a liquid may be used in a thermometer is from its F.P. to its B.P. Alcohol is sometimes used, but its only advantage over mercury is that it may read very low temperatures—down to about −130° C., the F.P. of mercury being −39° C. Alcohol thermometers are therefore used on scientific expeditions to the Arctic and the Antarctic.

The *advantages of mercury in the making of a thermometer* are many :—

(*a*) It does not (like alcohol), wet the tube, and therefore reads more accurately when the temperature falls.

(*b*) It is easily read (though alcohol may be coloured to enable it to be read also).

(*c*) It can read high temperatures, up to near 357° C., its boiling point (alcohol to only 78° C.).

(*d*) It expands uniformly, *i.e.* the increase in volume between 0° and 1° C. is the same as, say, between 90° and 91° C. (Alcohol does not expand uniformly.)

(*e*) It has a low "specific heat," *i.e.* it requires little heat to raise its temperature, or it is easily heated.

(*f*) It is a good "conductor of heat," *i.e.* the heat is rapidly transferred from one part of it to another : it is heated throughout and not only at one particular part.

EXPERIMENT 14. When the clear film of molten wax becomes dim it is solidifying or freezing, *i.e.* changing from the liquid state to the solid state. The temperature at which this takes place we may call the *solidifying point.* When the dimness begins to disappear it is melting or liquefying, and the temperature registered we call the *liquefying point.* Now our

eye is not quick enough to detect the exact instant when these two changes take place ; besides, the process has gone a certain extent before it is possible even to see it, even though the eye were quick enough. Hence the solidifying point we read will be lower than it actually is, and the liquefying point will be higher than it actually is. We therefore take the mean of the two temperatures, and thus eliminate the possible errors for the M.P.

The following table gives the melting points and the boiling points of some common substances :—

Substance.	M.P.	B.P.
Water . .	0° C. (32° F.)	100° C. (212° F.)
Alcohol . .	−130° C.	78° C.
Mercury . .	− 39° C.	357° C.
Ether . .		35° C.
Turpentine . .		159° C.
Sulphur . .	114° C.	
Lead . . .	330° C.	
Tin . . .	233° C.	
Cast iron . .	1200° C.	

Physical Constants

Like the density of a substance, its melting point and its boiling point are very important to find. These are three of what are called the *physical constants* of a substance, and may be used to identify the substance. For example, a clear, colourless liquid

(1) whose density is found to be 1 gm. per c.c.,
(2) whose F.P. is 0° C., and
(3) whose B.P. is 100° C.

is certain to be water.

They are called " constants " because they do not vary for the substance if it is pure.

SECTION III

SOLUTION—EVAPORATION—CRYSTALLISATION—DISTILLATION

EXPERIMENT 15. When the first small quantity of powdered alum was shaken up in the water it disappeared. It is said to *dissolve* (distinguish from *melt*) in the water; the water is called the *solvent*, the alum the *solute*, and the liquid remaining the *solution*. A substance which may, like alum or sugar, be dissolved is said to be *soluble*. At first, when only a small proportion of the solute is dissolved, the solution is said to be *dilute*. On continuing to add more and more of the alum in small quantities at a time, the solution becomes more and more *concentrated*, and we come to a point when no more will dissolve. The solution is then said to be *saturated*.

A saturated solution at a certain temperature is one which will not dissolve any more of the substance already dissolved in it, without changing the temperature. Any solid which is in a liquid, and is undissolved, is said to be *suspended* in it. Hence to make sure we have a saturated solution we must continue to add the solute until some remains suspended.

On heating the test-tube, the alum that was suspended also dissolves, and even more alum may be dissolved. Thus the substance is more soluble the higher the temperature; or, in other words, *the solubility increases with rise of temperature*, the solubility being the mass of the solute dissolving in a certain mass of solvent, generally 100 gm.

On cooling the solution, some of the alum *comes out of solution*, showing that the solubility decreases as the temperature falls. If the particles are examined closely they will be found to be regular in shape. That is, they are *crystals*; we say the substance is *crystalline*. Most substances, when they solidify from the liquid state, or come out of solution (which is an example of the same thing, for in solution the solute is in the liquid form), do so in the form of crystals. They are said to *crystallise*, and the process is called *crystallisation*.

EXPERIMENT 16. When a substance dissolves, like salt in water, it is not lost, as the mass of the resulting solution is equal to the mass of the solvent and the mass of the solute together. We saw that when we boiled a liquid, like water or

alcohol, it was changed into a vapour at a constant temperature called the boiling point. Here, when we warm the solution, the volume of the liquid diminishes, the water goes off into the air in the form of vapour, though not at the boiling point. This process is called *evaporation*, which takes place from a liquid at all temperatures, though the higher the temperature, the greater is the rate of evaporation. The liquid is said to *evaporate*. From the solution it is only the solvent that evaporates, the salt remains as the residue, and we recover the same mass of salt as we dissolved, the reason being that the water is *volatile*, while the salt is not. A volatile substance is one that can be evaporated without turning into other substances. We could, of course, have boiled away the water, but in boiling, the vapour comes off in bubbles from all parts of the liquid, which spurts up out of the basin; hence we would lose some of the solute. In evaporation, on the other hand, the vapour comes off from the surface of the liquid only, and not in bubbles. The greater the surface of the liquid, then, the greater will be the rate of evaporation; hence the evaporating basins are made wide and shallow, and not narrow and deep.

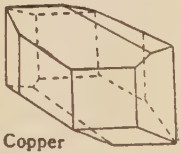
Note that to make sure that all the water is evaporated we repeat the process of heating until two successive weighings are the same. This is the scientific method.

Experiment 17. When sand is shaken up with water, it appears not to dissolve, *i.e.* it seems to be *insoluble*; but we cannot be sure just by looking at it. It may be that it is very slightly soluble. We therefore evaporate some of the liquid and find if there is any residue. There is none, so we conclude that sand is insoluble. On shaking up the mixture the salt dissolves, but the sand remains in suspension. To separate them we pour the solution through a paper which allows the liquid part to pass through, but retains the suspended matter. The paper is porous, *i.e.* full of little holes called pores, which are too small to allow solid particles to pass through them. The process is called *filtration*, the paper a *filter paper*, and the liquid coming through the paper the *filtrate*. If we evaporate the filtrate we recover the salt, the soluble portion. The sand left on the paper may be dried in an oven.

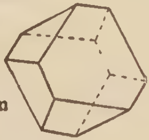
Experiment 18. When the hot solution of copper sulphate and alum is slowly cooled, the substances crystallise in larger

crystals than when rapidly cooled, as was the case of the alum in Experiment 16. If large enough, we find blue crystals of the copper sulphate and clear ones of the alum, which may be picked out separately, redissolved, and recrystallised in the pure form. The solution from which the substances crystallise is called the *mother liquor*. The process we have used to separate the soluble substances is called *fractional crystallisation*. It is seen to depend (1) on the fact that the substances have different solubilities—the less soluble of the two crystallising first; (2) on the fact that they are more soluble in hot solution than in cold; (3) on the proportions in which the substances are present.

The crystals of the two substances we have used are of different shapes. Perfect crystals of the two substances appear as shown in the figure, though it is difficult to get them perfect. Generally different substances differ in the shape of their crystals, though some classes of substances have the same shape, *e.g.* a large class of substances called the *alums* have the same crystalline form as the common alum we have been using. They are said to be *isomorphous* (Greek: *isos*=same, *morphe* =form). If a large crystal be broken gently, it is found to give smaller crystals of the same shape as the large one, because it has a tendency (called *cleavage*) to break along certain lines. This crystalline structure is due to the regular arrangement of the small particles composing the substance. If you break a piece of glass you find that it does not break into pieces of any definite shape: it has no cleavage and is said to be *amorphous* (Greek: *a*=without, *morphe*=form); amorphous substances are, therefore, substances which have no crystalline shape.



Copper sulphate



Alum

EXPERIMENT 19. It is evident that the clear liquid in the receiver is water. Hence we have recovered the solvent. When the solution is boiled, the water, being volatile, is evaporated, leaving the copper sulphate, which is not volatile, in the flask. The steam passes into the condenser where it condenses to water, and falls into the receiver. (A vapour is said to *condense* when it changes from the gaseous state to the liquid state.) The temperature of the steam is lowered

by the cold water which passes through the jacket tube. This cold water enters at the bottom, flows up through the condenser, and out at the top. If it entered at the top it would meet with the very hot steam and would probably break the glass. Besides it would be difficult to keep the jacket tube full of water if it were allowed to enter at the top. The whole process is termed *distillation*, and consists first of evaporation, then *condensation*. The pure liquid collected in the receiver is called the *distillate*.

N.B.—Distillation is the method employed to obtain a liquid in a pure condition, *i.e.* free from suspended matter, or matter dissolved in it.

EXPERIMENT 20. When a liquid consisting of water and alcohol is distilled, it begins to boil at about 78° C., the B.P. of alcohol. The temperature remains at this point for a time, while almost pure alcohol is distilling over, as shown by the smell, and the fact that there is no residue when the distillate is burned. It then rises more rapidly until nearing the B.P. of water ; all the time the liquid is distilling. The distillate caught during this range of temperature consists of both alcohol and water, as shown by the same tests—it smells of alcohol, and when ignited the alcohol may burn, and the water is left. On nearing the B.P. of water the temperature rises slowly, during which time almost pure water comes over, as shown by the same tests : it does not burn this time. We find that of the three portions we have collected, the greater quantities are the first and the third. To separate further, the whole process may be repeated with each portion. The volumes caught in the first and third receivers increase, while that in the second decreases. This process is termed *fractional distillation*, and depends on the fact that different liquids have different boiling points, the one with the lowest boiling point distilling first.

PURITY OF SUBSTANCES

We have seen that a pure substance—water or alcohol, for instance—boils away at a *constant* temperature called its boiling point. In Experiment 20 the liquid *began* to boil at 78° C., and *continued* boiling up to 100° C. It was not a pure substance. By finding the B.P. of a liquid, then, we can tell whether it is pure or impure. In the same way, the purity

of a solid may be tested by finding whether it all melts at a constant temperature or not.

N.B.—We cannot apply the density test to tell whether a liquid is pure or not because we could mix various liquids in certain proportions to give us a liquid having the same density as some other pure liquid.

SECTION IV

THE CHEMISTRY OF THE AIR—RUSTING—BURNING

Air: A Material Substance

Experiment 21. The flask has a greater mass before the air is sucked out than after. Hence the air must have mass. It is therefore composed of matter. If the clip be then opened gently the air is heard rushing into the flask to take the place of that sucked out. It is sometimes difficult to believe that there is such a substance as air, because we are so accustomed to it: it surrounds us always. In the same way it is quite reasonable to assume that fishes living in the depths of the ocean have no idea of the presence of water. We can, of course, bubble air through water, showing that it takes up space. Also, when the wind blows, we feel it moving. When we draw our hand rapidly through the air, we can also feel it—it must therefore be composed of a material substance.

Rusting of Iron

Experiment 22. When iron rusts we find that it gains in mass. Hence there must be some connection between the rusting and the gaining of some material substance. The question arises, where has the extra substance come from? The only substances in contact with the iron that could have supplied this extra mass were the air and the water. We infer then that it must have come from the air, or from the water, or partly from each of these. We shall find out.

Now, when we examine iron before rusting and again after rusting we see that it has different properties. Iron is grey and shiny (*i.e.* it has *metallic lustre*), has a distinct *metallic sound or ring*, can be hammered out, especially when hot (*i.e.* it is *malleable*), has a fairly high density (7·4 gm. per c.c.), and clings to a magnet when the latter is drawn through it. Iron rust, on the other hand, does not seem to have any of the properties of iron at all. It is reddish brown in colour, has no lustre or metallic ring, cannot be beaten out (it is brittle), has low density (4·5 gm. per c.c.), and is not attracted by a magnet. In fact, iron rust seems to be an entirely different substance from iron.

Chemical Change

When we dissolved alum or salt in water there was no change in mass, and when we evaporated the solution we recovered all the solute ; when we boiled water, and made it into vapour, it could be condensed again into water ; when ice melted it became liquid. Only the state or form of the substance was changed : the substance remained the same substance, whether it existed in the solid state (ice), or the liquid state (water), or the gaseous state (steam). These changes are all *physical changes*, i.e. *changes only in one or more of the properties of the substance*. But in the rusting of iron we have an entirely different substance formed, which has properties entirely different from the properties of iron. Here we have more than a physical change, we have a *chemical change—a change in which we have an entirely new and altogether different substance* (*or substances*) *formed from the original.* Of course, we can tell we have a new substance only by observing and testing the difference in physical properties. Hence we cannot have a chemical change without having at the same time physical changes.

We shall study many chemical changes ; in other words, we are going to study *Chemistry*—the branch of Science which deals with finding out what substances are composed of—*i.e.* the composition of substances. Hitherto we have not been concerned with their composition, but simply with some of their properties—*i.e.* we have been studying *Physics*.

Experiment 23. Iron can be kept any length of time in a vessel containing dry air (in which is a substance, called a

drying agent, that abstracts every trace of moisture from the air) without showing any sign of rusting. But if exposed for a short time to moist air, it does rust. Hence we infer that water is necessary before iron will rust. Two drying agents commonly used are strong sulphuric acid (a heavy, oily liquid, which must be handled very carefully, because it is extremely corrosive—it destroys most common substances) and calcium chloride (a white solid).

Experiment 24. We saw in Experiment 12 that before water begins to boil little bubbles of air which have been dissolved in the water are expelled. The inference, therefore, is that, unlike most solids, gases are less soluble in water at a high temperature than at a low temperature. Hence by boiling the water for some time we make sure that all the air dissolved will be expelled, and we have water entirely free from air. To make doubly sure that we have the iron in water so that no air can get at it, we stopper the flask tightly, and also plunge the mouth of the flask in more freshly boiled water. Although left in the water for some considerable time the iron does not rust. It is difficult to remove the stopper now, because the steam that was in the neck of the flask before the stopper was inserted has condensed to water, and the hot water has also contracted when it cooled, so that the stopper has been pressed further into the neck of the flask. If left now open to the air, the iron soon rusts, thus showing that before iron rusts, air as well as water is necessary.

Experiment 25. By inverting the test-tube mouth downwards in water, we enclose air above the water, the volume of which is the capacity of the tube—less the iron filings. On examining the apparatus after a few days, we find that the iron has rusted, and at the same time the water has risen up the test-tube. There must therefore be some connection between the rusting of the iron and the rising of the water. Some of the air originally in the test-tube has disappeared, and the water has flowed into the test-tube to take its place. Now we found in Experiment 21 that air has mass, and in Experiment 22 iron gains in mass when it rusts. We infer therefore that the air which has disappeared has been used up by the iron in rusting.

If the level be marked and the apparatus again left, it is found that the water does not rise right to the top of the

tube, but stops about one-fifth up the tube, and no matter how much iron is used (provided there is plenty), or how large or small a tube is used, it only rises about one-fifth.

The remaining air in the tube, composing four-fifths of the original volume, is not "ordinary" air, because it does not allow a taper to burn in it. It would seem, then, that there are at least two distinct kinds of "air" in ordinary air—(1) the "active" air, composing about one-fifth by volume, which is used up by iron when it rusts, and which allows a taper to burn in it; and (2) the "inactive" part, composing about four-fifths by volume, which extinguishes a lighted taper.

Fuming of Phosphorus

Experiment 26. The same conclusion is drawn in this experiment as in Experiment 25. The only difference is that, whereas iron rust is a solid, remaining in the test-tube, phosphorus rust, which forms the fumes in this experiment, dissolves in the water.

Burning

Experiment 27. From the last three experiments we have seen that in (*a*) the rusting of iron, (*b*) the fuming of phosphorus, and (*c*) the burning of magnesium in a confined space of air there is always one-fifth of the air used up; and always the remaining four-fifths of the air differs from "ordinary" air in the fact that it extinguishes a lighted taper. We are led to the conclusion, then, that *rusting, fuming, and burning are all similar processes*; the only difference being in the rate at which the process takes place, rusting taking longer than fuming, and burning taking place very rapidly.

We found that in the case of rusting, the mass of the rust was greater than the mass of the iron, and it may be shown that the mass of the product formed when phosphorus fumes is greater than the mass of the phosphorus.

It is also evident that the action in each case ceased because the one-fifth of the air had been used up, since all the phosphorus and magnesium had not disappeared. It would seem, therefore, that this one-fifth of the air differs from the other four-fifths. In other words, that there are two different kinds of "air" in ordinary air—(1) an "active" part, and (2) an "inactive" part.

Ordinary air	I. *Active air*	(*a*) composes $\frac{1}{5}$ of air by volume. (*b*) allows a taper to burn. (*c*) is used up when iron rusts. (*d*) is used up when phosphorus fumes. (*e*) is used up when magnesium burns.
	II. *Inactive air*	(*a*) composes $\frac{4}{5}$ of air by volume. (*b*) extinguishes a lighted taper. (*c*) is not used up when iron rusts. (*d*) is not used up when phosphorus fumes. (*e*) is not used up when magnesium burns.

For example, in a litre of ordinary air there are 200 c.c. of "active" air and 800 c.c. of "inactive" air.

Indestructibility of Matter

Experiment 28. When iron is rusted in a tightly stoppered flask we find that there is no gain or loss of mass. You will remember that when we rusted iron in an open crucible it gained mass from the air and the water. In this experiment, however, nothing can get into the flask during the rusting, and nothing can escape out of the flask during the rusting. There has been, as before, a chemical change. At first we had in the flask iron, water, active air, and inactive air; after rusting we have iron rust, water, and inactive air. Though there is no longer iron and active air, but instead of these two substances, one substance, iron rust, the iron and the active air have not really gone out of existence; they have not been annihilated, *i.e.* made into nothing; they still exist, but in another form, because the total mass of the substances taking part in the change has remained unaltered, *i.e. there is no loss of matter*. Now a very large number of experiments have been carefully performed in many problems besides the rusting of iron, and they all give the same result, namely, that *in any chemical change the total mass of the substances taking part in the change does not alter.*

At first sight this statement looks absurd. We burn coal in the grate, and are left with a very small quantity of ash, the mass of which seems exceedingly small compared to the mass of coal burned. Yet if we could catch all the products formed during the burning, and add their mass to that of the ash which remains, it would be found that the total mass is the same as the mass of the original coal along with the mass of the active air used up during the action. We may imagine

the whole process to take place in an enormous globe, say, whose mass could be found. Provided the globe were sealed, so that the products, which are mainly gases, do not escape, the coal would have disappeared as before, leaving only the ash, but there would be no change in the total mass.

The statement of the results of a large number of experiments all leading to the same conclusion is called a *Law of Nature*; that is, a law not made by man, like the laws of the country, but one which has been true from the beginning of time. It is, in fact, a kind of "shorthand" way, as it were, of expressing a truth. There are a large number of such laws. Although they are natural laws, still, Nature does not reveal them to man unless after patient investigation. In fact, one of the chief aims of Science is to discover these laws; in other words, to search for the true meaning of things.

Now, this law which we have in a way discovered for ourselves is called the *Law of the Indestructibility of Matter*, or, sometimes, the *Law of the Conservation of Mass*, which simply means that the stuff that things are made of cannot be destroyed. Nor can new matter be created—that is, made out of nothing.

When the stopper in the flask is removed and again replaced, and the total mass again found, it is greater, for air has rushed in to take the place of the active air which has been used up, viz. about one-fifth of the volume of the flask.

Experiment 29. When metals are roasted in air they form an ash, or, as it is often called in Chemistry, a *calx* (plural, *calces*). These calces are generally powders having no resemblance to the original metals; they are, in fact, entirely different substances. A chemical change has, therefore, taken place, and since the mass has increased, it is obvious that the metals have taken something from the air. The metal and this substance from the air are said to *combine* to form *one* new substance. The process—called *Chemical Combination—is the uniting of two or more simple substances to form one new and entirely different substance.*

If it were possible to pick out one solitary particle of this new substance it would not be a particle of metal, nor would it be a particle of air; it would be a particle of the calx, and every particle is the same as every other particle. It is reasonable to infer from the burning of the magnesium that it is the active air that has combined with the metals.

Lavoisier and the Discovery of Oxygen

We have suspected that when metals rust or burn in the air, they form calces by combining with the "active" gas in the air. The question arises: Can we get back the metals, and also get a sample of this "active" air? Can we get back the same mass of metals and the same mass and volume of "active" air that has given the calces? Now this was the very important question that Lavoisier, a famous Frenchman, asked himself. It was natural to expect that if this active air could be got by itself, it would allow things to burn more brightly than they would do in ordinary air, where there is also "inactive" air. Previous to the time of Lavoisier (the latter half of the eighteenth century) it was thought that when substances burned a material called *phlogiston* left the substance, and hence the mass of the ash formed was less than the mass of the original substance. It is a fact that a few experimenters had shown that this was not the case; but it was difficult for even chemists who had performed some of the experiments to discard the idea of phlogiston, even after the time of Lavoisier. Lavoisier had tried to regain the metal and the "active" air by heating the calx strongly, but failed until he heard that an Englishman called Joseph Priestley had succeeded, in 1774, in getting from mercury calx the metal mercury and an "air" in which a candle burned more vigorously than in ordinary air. He called it "vital" air. Here was what Lavoisier wanted; and he lost no time until he had heated mercury calx and got the "active" air he had been looking for. This "air" is what we now call *oxygen*, the name given to it by Lavoisier. The "inactive" part of the air he called *azote* (*i.e.* without life): we now call it *nitrogen*. Thus air consists of one-fifth of its volume of oxygen, and four-fifths nitrogen.

Three years before Priestley discovered oxygen it was discovered independently by the Swedish chemist Scheele, who had performed the experiment we did on the rusting of iron (Experiment 25), and had come to the conclusion that ordinary air is composed of two gases or "airs"—(1) *fire-air*, or oxygen; (2) nitrogen. He obtained his fire-air from a large number of substances; but his discoveries were not published before Priestley had heated mercury calx.

Though the discovery of oxygen is assigned to Scheele and Priestley, it was Lavoisier who realised the great importance

of the discovery, for he explained the real meaning of rusting and burning, and on this his fame as a chemist rests. He discovered no new substance.

Experiment 30. When mercury calx is gently heated, its colour changes from bright red through darker red, brown, and finally black. The black substance is still mercury calx, for if allowed to cool it returns to its former red colour. This change is therefore only a physical one. If the powder is more strongly heated, however, a further change takes place. A glowing splinter of wood, when introduced into the test-tube, relights or bursts into flame. It does not do this in ordinary air. Hence there must be some new gas in the test-tube ; this is the "active" air or oxygen of Lavoisier, or the "vital" air of Priestley. At the same time a "mirror" forms on the inside of the tube above the place where it was heated. On being examined, it is found to consist of small globules of a silvery liquid—it is mercury.

N.B.—*The fact that a glowing splinter of wood bursts into flame in oxygen is made use of to detect the presence of the gas.*

Chemical Decomposition—Compounds and Elements

We began with one substance—mercury calx—and by heating it strongly we have broken it up into two entirely different substances. Thus from a red powder we have got a dense silvery liquid and a clear, colourless gas. The mercury calx is said to have been *decomposed*. Thus *chemical decomposition is the breaking up of a single substance into two or more simpler and entirely different substances.* It is therefore the opposite of combination. We may write the action

$$\text{mercury calx} \xrightarrow{\text{is decomposed into}} \text{mercury} + \text{oxygen}.$$

Most substances have been decomposed, though not by simply heating. (You will learn that decomposition may be brought about by other means, though in most cases heat is required.) But there are a few—about ninety—which have never yet been decomposed by any process. The former are called *Compounds—pure substances which can be decomposed* ; the latter are called *Elements—substances which up to the present time have not been decomposed.*

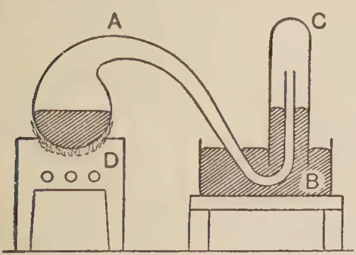
If it should happen, however, that a substance which has been considered an element be decomposed, then it is no

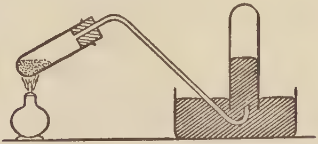
longer looked on as an element, but a compound. It is evident, then, that compounds must be made up of elements. Calces are compounds containing oxygen. Mercury has not been decomposed, nor has oxygen ; they are therefore elements. All metals are considered elements. Most of the elements are solids at ordinary temperatures ; two are liquids (mercury and bromine) ; and some are gases. The following list contains the more common elements :—

Aluminium.	Iodine.	Potassium.
Arsenic.	Lead.	Radium.
Calcium.	Magnesium.	Silver.
Carbon.	Mercury.	Sodium.
Chlorine.	Nickel.	Sulphur.
Copper.	Nitrogen.	Tin.
Gold.	Oxygen.	Zinc.
Hydrogen.	Phosphorus.	
Iron.	Platinum.	

Lavoisier's Historical Experiment

When Lavoisier heard of Priestley's decomposition of mercury calx, he proceeded to find out whether, in decomposing, the calx gives the same volume and the same mass of oxygen which the mercury used up when being formed. He took the apparatus as seen in the sketch.





He put a known mass of mercury into the vessel A (called a retort), which had a long, bent tube dipping into mercury (B) in a basin, the end reaching up into air contained in the inverted jar (C). He had thus enclosed a quantity of air filling A and C, whose volume he measured. He heated the mercury in A by means of a charcoal furnace (D). After two days he noticed black specks appear on the surface of the mercury in A, and at the same time the mercury rose in the

jar C, showing that some of the air was being used up. As he continued the heating, more of the scum formed on the mercury in A, and the mercury rose higher in C. There was no further diminution in volume of the air after twelve days. On cooling, the volume of air that disappeared was measured, and was found to be practically one-fifth of the total air in A and C. He collected carefully the scum—which had turned red on cooling—and found the mass of mercury left, and hence the mass of mercury forming the scum and also the mass of the scum.

The red powder—the calx—he now heated strongly in a separate tube, and found that he regained practically the same volume of gas and the same mass of mercury as had disappeared in the first part of the experiment.

Hence he arrived at the conclusion he had expected, namely, that when a substance is calcined or burned there is nothing lost, the total mass of the resulting substance is equal to the total mass of the substances uniting; and, on decomposing, the substances originally uniting are wholly recovered.

Experiment 31. No two members of the class have likely taken exactly the same mass of mercury calx. No matter how much or how little calx is decomposed, it is found that, if all is decomposed, it gives off 7·4 per cent. of its mass as oxygen, the remaining 92·6 per cent. being mercury. It would appear, therefore, that the percentage composition of the calx is always the same. This is a general and extremely important property of all compounds. A very large number of experiments have been performed, and in all cases it is found that "*the same chemical compound always has the same elements in it, and these elements are always present in the same proportion by mass.*" This is another law, called the *Law of Constant Composition*, and is sometimes stated "*compounds have a constant composition.*" For example, no matter how, where, when, why mercury calx has been made, provided it is pure, it contains both mercury and oxygen, always mercury and oxygen, and nothing but these two elements; and, also, it contains 7·4 per cent. of its total mass of oxygen and 92·6 per cent. of its mass of mercury, never any more or less of these percentages.

What is true of mercury calx is also true of magnesium calx and phosphorus fumes. Thus in every 5 gm. of magnesium calx there are always 3 gm. of magnesium and 2 gm.

of oxygen; or in 10 tons of magnesium calx there are 6 tons of magnesium and 4 tons of oxygen.

By finding the percentage composition of a compound we may be able to identify it. For example, if we have a red powder like mercury oxide, and find by experiment that it contains 9·3 per cent. of its mass as oxygen, we may be sure it is not mercury calx, but a compound called red lead.

SECTION V

THE CHEMISTRY OF THE AIR—OXYGEN—NITROGEN

EXPERIMENT 32. When *potassium chlorate* is gently heated it crackles. This is the noise made by the larger crystals being split up by the heat into smaller crystals of the same substance. The change is therefore a physical change. On further heating the substance melts or fuses, but if allowed to cool it becomes solid potassium chlorate again. The fusing is thus also a physical change. If the liquid chlorate is further heated it seems to boil, but it is not really boiling, for oxygen is being given off. The little bubbles observed rising through the liquid are not bubbles of potassium chlorate vapour, as would be the case if it were simply boiling. They are bubbles of oxygen, and the liquid is said to *effervesce* or *fizz*. (You see *effervescence* or *fizzing* taking place when you open a bottle of aerated water.) This effervescence, therefore, is a chemical change; the potassium chlorate is being decomposed. On continuing the heating the liquid is observed to become thicker, and oxygen is given off in large quantities. Finally, when no more gas is evolved, a white solid, called *potassium chloride,* is left. Thus

$$\text{potassium chlorate} \xrightarrow{\text{is decomposed into}} \text{potassium chloride} + \text{oxygen.}$$

When the black powder called *manganese* (not magnesium) *dioxide* is heated, no change seems to take place; no oxygen is evolved unless it is heated to a very high temperature.

Experiment 33. When potassium chlorate is heated just until it fuses, no oxygen is given off; but if a small quantity of manganese dioxide is added to the molten chlorate, oxygen is immediately given off freely. Now we have seen that potassium chlorate does not alone give off oxygen until the molten substance is further heated, and manganese dioxide alone gives off no oxygen unless heated to a very high temperature. We are led to the conclusion, therefore, that the oxygen must come from the potassium chlorate at a lower temperature when mixed with manganese dioxide than when heated alone. The manganese dioxide may be shown to have the same mass at the end of the experiment as before heating; yet it seems to hasten the rate at which potassium chlorate gives off its oxygen. We have here a very interesting example of what in chemistry is called *catalysis*. The manganese dioxide in this case is called a *catalyst* or *catalytic agent*—that is, "*a substance which hastens the rate of a chemical change without being itself altered at the end.*" It may, of course, and probably does, undergo some change *during* the action, but it is found unaltered *after* the change.

Note.—Manganese dioxide is not always used as a catalyst, but only in the preparation of oxygen from potassium chlorate. In other chemical actions it is an essential substance without which the action could not proceed, and after which it no longer exists as manganese dioxide.

Preparation of Oxygen

Experiment 34. The method employed in this experiment of collecting a gas is termed "*collecting by displacement of water*," or simply "*over water*." The most striking property of the gas oxygen is its causing a glowing splinter of wood to relight, and this is the *test* applied to detect its presence. If a clear, colourless, odourless gas causes a glowing splinter to burst into flame, then the gas is *oxygen*.

If iron filings are allowed to rust in oxygen enclosed over water, the water rises to fill the entire jar. In other words, provided there is sufficient iron, it will combine with all the oxygen. Phosphorus and magnesium burn in oxygen much more brilliantly than they do in air. This is just what we should expect, for in burning, oxygen is being used up, and in air there is nitrogen present, which does not assist, but hinders, the burning. In scientific language we say that oxygen

supports combustion vigorously, or is a very good *supporter of combustion*, i.e. *a gas which allows things to burn in it.* Air is thus a supporter of combustion. Substances which burn easily are said to be *combustible*, *e.g.* wood, paper, coal.

The products of the burning of elements in air or in oxygen are called *oxides*. An oxide is *a compound of two elements, one of which is oxygen.*

The calces of metals are oxides, *e.g.* mercury oxide. Potassium chlorate is not an oxide though it contains oxygen, for it is a compound of oxygen and another compound, potassium chloride. (You will learn later that air also is not an oxide.)

(If a compound contains only two elements its name ends in *-ide*, *e.g.* a sulphide is a compound of sulphur and one other element.)

Oxygen has no effect on litmus paper.

When oxygen is shaken up with a small quantity of air-free water, and then the jar is opened under water, more water rises into the jar. The first quantity of water dissolves some of the oxygen, and so more water enters to take its place. This is the usual method of finding whether a gas is soluble or insoluble in water. Oxygen is moderately soluble in water. As with all gases, oxygen is less soluble at high temperatures than at low temperatures; they are unlike solids in this respect.

If a jar of oxygen is inverted over a jar of air, mouth to mouth, and the cover removed, the oxygen is found to have flowed into the lower jar, showing that the gas is denser than air.

Oxygen, when shaken up in lime water, has no effect on it.

Summary of the Properties of Oxygen

Oxygen—

(1) is a clear, colourless, tasteless, odourless gas.
(2) rekindles a glowing splinter of wood; is an excellent supporter of combustion.
(3) has no effect on litmus.
(4) is moderately soluble in water.
(5) is denser than air.
(6) has no effect on lime water.

Oxidation—Burning—Combustion

From our experiments in the Chemistry of the air and oxygen we infer that the rusting of iron, the fuming of phosphorus, the burning of magnesium, or of a taper for that matter, are all one and the same chemical action, *i.e.* combining with oxygen, or *oxidation*, the only difference being in the rate at which oxidation takes place. These processes (1) do not take place when there is no oxygen, and (2) they take place more rapidly in pure oxygen than in air where there is also nitrogen. We are therefore led to the conclusion that rusting, fuming, and burning *mean* oxidation. If the oxidation takes place rapidly, heat and light are given off and we say the substance *burns*. Thus *burning* or *combustion* is *oxidation when heat and light are given off.* In all cases of oxidation heat is given out, even in the rusting of iron; but it may be so slowly that it is not detected.

The burning of coal is perhaps the most important chemical change with which we are familiar. Coal is mostly composed of the element carbon, which is oxidised to form the gas, carbon dioxide; and the oxidation of this carbon gives out a great deal of heat. In fact, this is the usual way of producing heat—by the chemical change known as combustion. Now there are two great classes of chemical changes—according as whether the change *gives out heat*, or *requires heat to be supplied*. The former are said to be *exothermic*; the latter *endothermic*. As a general rule chemical combination (and therefore oxidation and burning) is exothermic, and the opposite, chemical decomposition (*e.g.* decomposition of potassium chlorate into oxygen and potassium chloride) is endothermic.

Acids and Alkalies

Experiment 35. When substances like sulphuric acid, hydrochloric acid, nitric acid, and vinegar are added to the blue dye, litmus, the colour is changed to red. This property is possessed by a large number of substances called *acids*. If, however, other substances like caustic soda, caustic potash, ammonia are added to litmus the blue colour remains unchanged. But if the litmus solution be previously acidified, and therefore turned red, these substances restore the blue colour. A substance which does this is called an *alkali* (plural, *alkalies*). It is important to note that if the substance

—acid or alkali—be added gradually to the other—alkali or acid—it does not immediately change the colour, but only when a sufficient quantity has been added, determined by the amount of the other present. We can therefore infer that it would be possible to add just enough of acid or alkali to make a solution which contains neither acid nor alkali. Such a process is called *neutralisation*. Thus if you get some acid on your clothes it is advisable to wash the spot with an alkali, preferably ammonia. A third class of substances, like common salt or sugar, neither turn litmus red nor restore the blue colour to reddened litmus. They are said to be *neutral to litmus*. We found that oxygen is neutral to litmus.

Instead of using litmus dye in the form of a solution, it is more often used in the form of *litmus paper*, *i.e.* paper that has been dipped in the solution and allowed to dry. We have litmus paper in the two colours, and by dipping it into a solution we can determine whether the solution is *acid*, *alkaline*, or *neutral*.

It is important to note that the substance to be tested must be in solution, at least to a slight extent, before it has any effect on litmus.

We can find out a lot about substances, simply by determining to which of these three classes they belong.

Oxides

Experiment 36. From this experiment we find that

I. The oxides of carbon (*carbon dioxide*—a clear gas), sulphur (*sulphur dioxide*—a clear gas), and phosphorus (*phosphorus pentoxide*—white fumes) dissolve in water and form acids. These oxides are therefore called *acidic* (or *acid-forming*) *oxides*.

II. The oxides of sodium, calcium, and magnesium form *alkalies* in water; they are called *basic oxides*.

III. The oxides of iron and copper are *neutral* to litmus. (Note the oxide of iron differs from iron rust—which is also an oxide of iron.)

Again we note that (*a*) the *acidic oxides* are oxides of *non-metals*; (*b*) the *alkaline oxides* are oxides of *metals*; (*c*) the *neutral oxides* are also the oxides of *metals*.

It may be due to the fact that the oxides of iron and copper are insoluble in water that they have no action on litmus.

Copper oxide is also a basic oxide. Hence we have the following classification:—

$$\text{Oxides}\left\{\begin{array}{l}\text{Acidic---oxides of non-metals.}\\ \text{Basic}\left\{\begin{array}{l}\text{soluble---alkaline}\\ \text{insoluble---neutral}\end{array}\right\}\text{oxides of metals.}\end{array}\right.$$

Here, then, is the important chemical difference between metallic and non-metallic elements:

A metal is an element which forms at least one basic oxide; a non-metal is an element which forms an acidic oxide.

N.B.—You must guard against thinking that the elements themselves are basic or acidic: it is their *oxides* that are basic or acidic.

The name *oxygen* was given to the gas by Lavoisier, because he thought that all acids contain oxygen, the word being derived from two Greek words meaning "acid-producer."

EXPERIMENT 37. When air is passed over red-hot copper the copper unites with the oxygen, forming black oxide of copper, and the nitrogen passes through the apparatus and is collected in the bottle. (1) It is a clear, colourless, odourless gas. (2) A lighted taper is extinguished and the gas does not catch fire. It is therefore not a supporter of combustion, nor is it combustible. (3) It is neutral to litmus; and (4) hardly soluble in water. It escapes in a very short time from a jar left standing open, and remains longer in one left inverted: we infer that (5) it is less dense than air. (6) It has no effect on lime water. We thus see that nitrogen has mostly negative properties.

MIXTURES AND COMPOUNDS

EXPERIMENT 38. Iron filings are dark grey in colour; when thrown into water they sink; they cling to a magnet when it is drawn through them. Sulphur, in the form of flowers of sulphur, is primrose yellow in colour, floats on water, and is not attracted by a magnet. From these properties we can predict that the colour of a simple mixture of these substances will be a kind of grey, intermediate between the yellow of sulphur and the dark grey of iron. A little more sulphur simply makes the colour a little nearer yellow, and a little more iron a little darker grey; but neither of these

alters the general properties of the mixture. That is, *the composition of a simple mixture may alter*—it is not constant. When some of the mixture is thrown into water we can predict that the iron will sink, while the sulphur will remain on the surface; and when a magnet is drawn through the mixture, the iron will cling to the magnet but the sulphur will not. Thus the *components* of the mixture may be separated without a chemical change, *i.e.* by a physical process. (We have already used such a process in each of solution, filtration, crystallisation, distillation.) When the substances are simply mixed there is no rise in temperature. Again, the particles of iron and sulphur in the mixture may be distinguished, if not by the unaided eye, then by a lens; and if one single particle of the mixture could be picked out it would be a particle of iron *or* a particle of sulphur, *i.e.* every particle is *not* the same as every other particle.

When the mixture is heated it begins to glow, and if the tube be immediately withdrawn from the source of heat it continues to glow until the whole mass is red hot. It is evident, then, that a chemical change is taking place, and seeing it is exothermic, it must be *combination*; the iron and the sulphur are combining to form a compound, called iron sulphide. The compound has properties entirely different from its *constituents*. It is black in colour; when thrown into water it does not partly sink and partly float; when a magnet is drawn through it the iron is not attracted, leaving the sulphur. These properties could not be predicted from those of iron and sulphur. On examining the sulphide with a lens we cannot distinguish two different kinds of particles. If one single particle could be picked out, it would be a particle of iron sulphide; every particle of it *is* the same as every other particle. It is a *pure* substance. Being a compound, it has a constant composition.

The following table contains the chief distinctions between a mixture of substances and a compound of the same substances:—

Mixtures.	*Compounds.*
1. The components may be separated without a chemical change.	The constituents cannot be separated without a chemical change.
2. The properties resemble those of each component and may be predicted from them.	The properties are entirely different from those of each constituent, and hence cannot be predicted.

[*Continued overleaf.*

Mixtures.	*Compounds.*
3. There is no change in volume or temperature when substances are simply mixed.	There is generally a contraction in volume and a rise in temperature when substances combine to form a compound.
4. The components may be present in any proportion.	The constituents are present in fixed proportions.
5. The separate particles are not all of the same kind.	The particles are all of the same kind.

We are now in a position to classify substances further:

Substances.

- Elements.
  - Metals. *e.g.* iron, magnesium, sodium, calcium, mercury
  - Non-metals. *e.g.* carbon, sulphur, phosphorus, oxygen, nitrogen
- Non-elements.
  - Mixtures. *e.g.* granite, plum pudding, air
  - Compounds. *e.g.* iron rust, sugar, marble, potassium chloride, mercury oxide

Experiment 39. When 200 c.c. of nitrogen and 50 c.c. of oxygen are allowed to mix we get 250 c.c. exactly of a gas which has all the properties of ordinary air. It allows a taper to burn in it, but it does not rekindle a glowing splinter. There is no contraction in volume and no rise in temperature. We are therefore led to consider the air as a mixture of gases and not as a compound.

Reasons for Regarding Air as a Mixture and not a Compound

1. The composition of the air is not exactly constant—there are slight variations. For example, the air over large cities contains a less percentage of oxygen than the air in the country.

2. The properties of air are intermediate between those of oxygen and nitrogen and may be predicted from these.

3. There is no change in volume or temperature when nitrogen or oxygen are mixed to form air.

4. Air which has been dissolved in water and then expelled by boiling, and examined, is found to contain more than one-fifth of its volume of oxygen, and therefore less than four-

fifths nitrogen. This is owing to the fact that oxygen is more soluble than nitrogen. [If air were a compound it would dissolve as a whole, and the composition of dissolved air would be the same as undissolved air.]

5. The oxygen and the nitrogen in the air may be separated without a chemical change, *e.g.* by cooling the air sufficiently it condenses to the liquid form, and liquid air can be fractionally distilled into nitrogen and oxygen: it does not have a constant boiling point. [This is the method by which oxygen is now prepared on a large scale.]

SECTION VI

THE PHYSICS OF THE AIR—PRESSURE

Experiment 41. *A*—I. If a piece of tubing be dipped into water and the air sucked out, the water rises in the tube. The movement of the water is caused by the air pressing down on the surface of the water in the basin.

II. In the experiment with the bottle the weight of the water would tend to make it flow out; but it is prevented by the air pressing downwards on the surface of the water in the basin, for the air is the only body in contact with it unless the rigid sides of the basin.

III. When the rod is struck sharply at the projecting end, the other end is lifted up easily. Very little difference is experienced when the newspaper is laid folded on it—there is only the weight of the paper pressing down upon it. But when the paper is spread out and the rod struck sharply, the other end rises not at all, or only with great difficulty. In fact, there is the danger that the stick may be broken. This time, instead of having only the weight of the paper as before (for it has not increased), we have in addition the pressure of the air over the whole surface of the paper, where before we had it on a much smaller area.

IV. In the experiment with the boy's sucker it is prevented from moving, when pulled, by the great pressure of the air downwards on the leather.

B—I. In the first part of this experiment the weight of the water is downwards, and still it remains in the tumbler. It must therefore be balanced by the pressure of the air, which must be upwards, as the water and the air are the only two bodies acting on the paper.

II. When the flask with the holes in it is lifted out of the water with the thumb on the mouth, the water is prevented from flowing out by the upward pressure of the air, because there is nothing but the air in contact with the water at the holes in the bottom of the flask. If, however, the thumb be removed the water does flow out, because the air gets in and the downward pressure balances (practically) the upward pressure, and the water is forced downwards by its own weight.

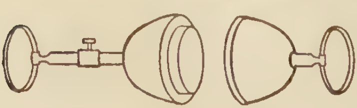
III. In the last part of the experiment, when water is poured into the funnel, some of it enters the flask by its own weight. This displaces some of the air inside, and it presses upwards through the funnel, and even forces out some of the water in the funnel.

C—I. The sucker may be made to stick on a smooth surface, whether horizontal, vertical, or sloping, showing that the air presses in all directions. On inserting the knife in each case the sucker was easily lifted. This was owing to the air pressing up under the sucker, and thus balancing the pressure downwards.

II. On sucking some of the air out of the funnel, the rubber film curves inwards, showing the air pressure ; and if turned in all directions there is no further movement either inwards or outwards, showing that the air is pressing equally in all directions.

Experiment 42. The cold water condensed the steam above the water in the flask and thus reduced the pressure considerably inside, while the pressure of the air outside in all directions was so great that the walls of the flask were not strong enough to resist, showing the enormous pressure exerted by the air.

Historical. The great pressure of the air was strikingly shown in 1651 by a German, Otto von Guericke, at Magdeburg. He procured two strong hemispheres of copper, about 2 ft. in diameter, which fitted



into each other (see figure). One was provided with a tap, by

which the air was sucked out of the hemispheres by means of an air pump he had invented. The tap was then turned to prevent any air re-entering. So great was the pressure of the air that it required eight horses pulling each way to separate the hemispheres. Small hemispheres, called "Magdeburg hemispheres," are still made to show the same thing.

EXPERIMENT 43. When the piston of the cycle pump is first pushed down, it is very easy to do so; the piston simply pushes the air in front of it, and it issues through the hole. But when it is pushed down without any air being allowed to escape, we find it is difficult to push; and the farther we push it, the more difficult it becomes. We have the same amount of air in the cylinder as we had at first, but it has been squeezed into a smaller space, *i.e.* it occupies a smaller volume. It is evident that the air is now exerting a greater pressure, for if the thumb be now removed, the air comes rushing out with a great force. In other words, the air has been *compressed*.

If the hole be closed while the piston is up a very little, and the piston drawn out without any more air getting in, it is again difficult to draw out. Here, on pulling the piston out even a little, the air in the cylinder occupies a larger space, *i.e.* it has a larger volume. If the thumb be now removed air rushes in, showing that the pressure of the air inside has been reduced; the gas this time is said to have been *attenuated*.

EXPERIMENT 45. (*a*) When we press an india-rubber ball or a balloon full of air we feel that it becomes more and more difficult to press. The air inside is being compressed into smaller volume. On releasing the pressure, the air resumes its former volume, and the ball its former shape. We thus see that the air and the rubber are elastic.

(*b*) When we close the hole of the cycle pump, and push the piston down sharply, we compress the air in the cylinder into smaller volume, and feel the air acting as if it were a cushion. On releasing the piston it springs back sharply because of its elasticity; it tries to resume the volume it occupied before being compressed. It acts in much the same way as a compressed spring in an easy-chair or a bed mattress.

If, again, the hole be closed after the piston is pushed down almost to the end, and the piston be sharply drawn up and then let go it once more springs back. This time we have at first increased the volume of air, and it tries to get back again to its former volume because of its elasticity. Thus the air, in

this respect, resembles an elastic cord used as a catapult—where a stretched cord, in trying to resume its former length (unstretched length), is used to propel a missile.

(*c*) The air in the large bottle, being compressed, tries to get its former volume, and in so doing forces the water out by the nozzle causing a fountain.

All these experiments illustrate the elasticity of the air, or what was called the "*spring of the air*" by Robert Boyle, who (in 1662) was one of the first scientists to perform experiments on the pressure of the air. Boyle was the son of the Earl of Cork, though he preferred to devote himself to science and remain a commoner. The name of Boyle is one of the most famous in the history of science.

SECTION VII

PHYSICS OF LIQUIDS AND GASES—THE BAROMETER

Mass and Weight

Experiment 46. If we pull out a spiral spring or a rubber cord, we must exert a force, and if the force is withdrawn the cord or spring assumes its original length, *i.e.* it is elastic. If one end be fixed and a mass be added by a suitable means to the other, then it is again stretched by the force of gravity, or the weight of the mass added. If the mass be removed the spiral springs back again. If a larger mass be added, there is a greater weight, *i.e.* force, and the spiral is farther stretched. On examining the table completed in the experiment, it is evident that twice the weight causes twice the extension, and three times the weight causes three times the extension, and so on. (By a *weight* of 1 gm. we mean the force with which the earth pulls a mass of 1 gm., and so on.) Thus if a weight of 10 gm. stretches the spiral through 1 cm., then a weight of 30 gm. will stretch it 3 cm., and a weight of 54 gm. will stretch it 5·4 cm. This is expressed scientifically in *Hooke's Law*, which states that "*the amount of stretching of an elastic cord is proportional to the weight* (*or force*) *stretching it.*"

We have in the experiment made what is called a "spring balance"—an instrument by which we can measure directly

the weight of a body—and, since the weight of a body is a force, we can thus employ the spring balance to measure forces, and therefore pressures.

Spring balances are manufactured, and graduated ready for use.

Gravitation

With the beam balance we simply compare masses. If you asked the grocer for a pound of butter, very probably he would put on one pan a piece of brass whose mass is 1 lb. and on the other as much butter as balances this mass, and would hand you a lump of butter which he says is 1 lb. If now you hang this lump on a spring balance graduated to read lb. you would find it really weighed 1 lb. But if you could carry the lump, say, to the North Pole, and weigh it there by the spring balance, you would find that it would stretch the spring in the balance farther; that is, it would *weigh more* than 1 lb., though obviously it has not gained any *mass*, as would be shown by the beam balance. It still contains the same amount of matter. Again by weighing, say, at the Equator, you would find it did not stretch the spring as it did originally, *i.e.* it *weighs less* than 1 lb., though, as before, it has still the same mass. It is evident, therefore, that the weight of a body varies: it depends on where we weigh it.

If we could carry the butter up in a balloon, and weigh it very high up above the earth, once more we would find it to weigh less than 1 lb. if tested by the spring balance. Now by going *up* we mean we are going farther away from the centre of the earth, and by going to the Equator along the surface of the earth, we are also going away from the centre. (The earth is an *oblate spheroid*, *i.e.* a solid similar to a sphere, but which bulges out at the Equator. This shape is due to the rotation of the earth on its axis.) And the Poles are nearer the centre. Thus the nearer bodies are to the centre of the earth the greater are their weights.

This is a particular example of a very important law of Nature, called the *Law of Gravitation*, discovered by an Englishman, Sir Isaac Newton (1642–1727), perhaps the greatest man of science that ever lived. This law states that every particle of matter in the Universe (including the earth, moon, sun, stars) attracts every other particle with a force depending on their masses and their distance from one another. The greater the masses the greater is the attraction,

but the greater the distance apart, the less the attraction. It is the property of all matter as stated in this law that keeps the earth, sun, moon, and stars in their paths.

Applied to the earth and bodies near it, the law is sometimes referred to as the *Law of Gravity*. Thus it is easy to descend a hill, because the earth is pulling us downwards ; but difficult to ascend. On account of gravity, water flows downhill, and thus rivers make their way to the sea. The oceans, on the other hand, cannot flow any nearer the centre of the earth ; and they do not flow off the earth, because of the attraction of gravity.

The story is told of Newton that the idea of gravitation occurred to him on seeing an apple fall from a tree towards the ground, which set him wondering why it moved downwards, and not upwards, or horizontally, or in any other direction. Be this as it may, it is almost certain that he deduced the law mathematically from three other laws enunciated by the astronomer Kepler, and known as "Kepler's Laws," which deal with the motion of the planets round the sun, and which he deduced from direct observation of their movements.

Pressure of Liquids and Gases

Experiment 47. (*a*) When the holes in the can are opened, jets of water are forced out at right angles to the sides, from which we infer that the water is exerting a pressure. The highest jet is forced out least, the lowest jet most ; hence the greater the depth of liquid, the greater is the pressure the liquid exerts. If no more water is allowed to flow into the cylinder, the jets gradually diminish as the level falls. (The path traced out by each jet is called a *parabola*.)

(*b*) On pressing the rubber film gently, the air inside is compressed, and at the same time the liquid falls in the limb of the U-tube (next the water) attached to the rubber and rises in the other. And the more we press the greater is the movement in the U-tube. We can thus use this instrument as a measure of the pressure on the skin, for when the pressure is released the liquid resumes its original position. Now when the funnel is lowered into the water, the gauge indicates that the water exerts pressure, and the farther it is lowered the greater is the pressure. On being gradually withdrawn from the water the gauge also shows the pressure to become less.

EXPERIMENT 48. The experiment clearly proves that the pressure at a certain depth in a liquid, which is at rest, is the same in all directions—downwards, upwards, sideways. This is a property common to all fluids, *i.e.* liquids and gases, and we have already shown it to be true of air.

EXPERIMENT 49. When the glass disc is put into water it sinks on account of its weight, *i.e.* the pull the earth has on it. Also it does not stick to the bottom of the cylinder for the same reason. But when the cylinder is plunged into water, the disc does not fall away, but remains on the end of the cylinder. Now the only forces acting on the disc are (1) its weight downwards, and (2) the pressure of the water upwards. It is the latter pressure, therefore, which prevents the disc from falling off.

At the same time water is flowing into the cylinder through the space between the disc and the cylinder, and it continues to flow until the levels outside and inside are the same, when it stops. And whenever the levels are the same the disc falls away because of its weight. At that instant the upward pressure of the water on the disc is balanced by the downward pressure of the water. Now the downward pressure is clearly the weight of the water above the disc. Hence the upward pressure, and therefore *the pressure in all directions at a certain depth in a liquid is measured by the weight of the liquid above.* Thus we can express the pressure in units—*e.g.* a pressure of 100 lb. on the area of the disc, say 4 sq. in., or a pressure of 25 lb. per sq. in.

Note that the liquid inside the cylinder rose until it attained the same level as the liquid outside—rapidly at first, and gradually more slowly. This fact has been expressed by the phrase, "*water seeks its own level.*" Look at diagram (*b*): we have the water at two different levels and therefore at two different pressures; the pressure at X is greater than the pressure at Y (since pressures are measured by the weight of liquid above), though X and Y are at the same level. We have therefore a difference of pressures at points on the same level, and hence *a movement of the liquid, from point of greater to point of less pressure, until the pressures are equal,* i.e. *until "the liquid has reached its own level."*

This is the fundamental law in the science of fluids, and really embraces the following four statements:—

I. When the pressures in a liquid at all points on the

same level are the same, the liquid is at rest; and, conversely,

II. When a liquid is at rest, the pressures are the same at all points on the same level.

III. When a liquid is moving, the pressures are not the same at all points on the same level, *i.e.* there is a difference of pressures; and, conversely,

IV. When the pressures are not the same at all points on the same level in a liquid, the liquid moves (until the pressures are the same).

N.B.—The difference of pressures, measured generally by the difference in levels (in lineal units as, *e.g.* feet), is termed a "head of liquid."

This law applies to all fluids—liquids and gases.

Experiment 50. At the instant the thumb is withdrawn after inverting the tube in the mercury, we have the state of affairs as in diagram (*a*). But the mercury immediately moves downwards (and this must therefore be the direction of the greater pressure). There must consequently be unequal pressures at points on the same level. As a suitable level, let us take that of the surface of the mercury in the basin. Here we have the air pressing downwards. At the same level inside the tube we have the head of mercury AB pressing downwards. Hence this latter pressure must be greater than the former, the atmospheric pressure. This explains why the liquid falls.

(a) (b)

But it stops falling when the mercury has descended about 6 in. or so. In this position, then, we have the atmospheric pressure equal to the head of mercury, and a condition of affairs as in diagram (*b*).

The space above the mercury contains no air, as none was allowed to enter; it is practically a *vacuum*. Hence the pressure of the air is measured by the weight of the head of mercury.

If the barometer be tilted, the mercury in the tube remains at the same horizontal level, and as the top of the tube is brought below this level the mercury hits it with a sharp click. There is no air to break the mercury up into small drops, so it meets the tube as a solid lump. In reading the height of the

barometer we must measure the *vertical height*, and not the *length* of the tube.

The height of the mercury barometer is found to be about 75 or 76 cm. But by the term "*normal pressure*" of a gas we mean exactly 76 cm. of mercury pressure.

On calculating the atmospheric pressure we find it to be approximately 1000 gm. on every sq. cm., or nearly 15 lb. per sq. in.

By taking readings of the barometer on successive days over a long period, we discover that the height varies from about 28·7 in. to over 30 in., that is, the pressure of the air is not always the same. The chief cause of the variation is the relative amount of water vapour in the air. Water vapour is less dense than dry air ; hence, if the air is acquiring more and more moisture, it is becoming less and less heavy, and cannot therefore support such a great head of mercury, with the result that the barometer falls. If, then, we find the barometer falling, we infer that the air is becoming more and more moist, and we shall probably have rain. If it rises, we infer the opposite.

Height of Water Barometer

We have seen that the pressure of the air balances a head of mercury of about 30 in. If we used water instead of mercury, the water column would evidently be 13·6 times this height, *i.e.* 34 ft. This is often referred to as the height of the water barometer. By referring to our experiment in Section VI with the suction pump, we remember that it is the pressure of the air that raises the water in the pump. A suction pump, therefore, cannot raise water more than 34 ft. above the surface of the water in the well or cistern (in practice only about 32 ft.). It was the discovery of this fact that led to the construction of the barometer. In 1640 the Duke of Tuscany, in digging a well, found that the water could not be raised above 32 ft. and asked the great *Galileo* for an explanation. Galileo died in 1642 before he had completed an experiment he had begun to solve the riddle. In fact, he had surmised that if water could be raised 32 ft., mercury should be raised about one-thirteenth of 32 ft., or about 30 in. His pupil *Torricelli* then performed the experiment we have been discussing. The space above the surface of the mercury in the tube is called the "Torricellian vacuum."

Experiment 51. (*a*) At first when the water is boiling freely the temperature is about 100° C. (or 212° F.). On the tube being closed with the fingers the steam is prevented from issuing, and the B.P. rises. When the tube is now opened the steam issues in greater volume than before, showing the pressure inside the flask had been increased. Hence *by increasing the pressure on a liquid we raise the boiling point.*

(*b*) When the burner is extinguished and the flask removed with the tube clipped, the water stops boiling. We have then inside the flask above the water only steam. When cold water is poured over the flask now, it recommences to boil, without heat being applied. And it boils at a temperature lower than 100° C. (or 212° F.). The boiling continues for a time while cold water is being poured on the flask, and the temperature may be as low as 80° C. The cold water of course condenses some of the steam to water, and hence reduces the pressure above the water, as is shown by the flatness of the rubber behind the clip. On gently opening the clip we hear the noise of the air rushing into the flask where the pressure is low. Hence *by decreasing the pressure on a liquid we lower the boiling point.*

Experiment 52. As the water in the flask is being heated, that in the tube expands, and the level of mercury falls in the closed limb. When the water is boiling that in the tube evaporates also, and we have steam above the mercury. At the same time the levels of the mercury in both limbs are the same, and hence the pressure of the steam in the closed end (which is the pressure on the mercury in that limb) must equal the pressure on the mercury in the open limb. Now this is open to the air, and therefore the pressure there is atmospheric. Hence *when a liquid boils in a vessel open to the air, the pressure of the vapour from it equals the pressure of the air.*

Now we have already defined the boiling point of a liquid as the temperature at which it boils; but we have now found that that temperature depends upon the pressure to which it is subjected; and as the atmospheric pressure is not always the same, hence the temperature at which a liquid boils in an open vessel is not always the same. Seeing also that the B.P. is a very important physical constant, we must therefore fix the pressure at which the true B.P. is to be determined. This is taken as normal pressure, *i.e.* 76 cm. of mercury.

Hence we define the boiling point as "*that temperature at which the pressure of the vapour from a liquid is equal to a pressure of* 76 *cm. of mercury.*" Only at this pressure does water boil at 100° C. or 212° F. By careful experiment it has been found that the boiling point of water rises or falls by ·04° C. for an increase or a decrease respectively of 1 mm. mercury pressure. Thus if the barometer is at 75·8 cm., the true boiling point of water is $(100-2\times\cdot04)°$ C., *i.e.* 99·92° C.

SECTION VIII

PHYSICS OF LIQUIDS—PRINCIPLE OF ARCHIMEDES—FLOTATION

Experiment 53. (*a*) As the brick is lowered into the water the pointer on the balance rises on the scale, indicating that the brick is weighing less, and the farther it is lowered into the liquid the less it appears to weigh, until it is totally immersed. Now none of the brick has been lost; that is, its mass is unaltered. And the pull the earth has on it is unchanged; that is, its actual weight is the same as before being lowered into the water. Hence the water must be exerting a pressure upwards—that is, in the direction opposite to the weight of the brick.

As the brick is gradually withdrawn from the water the weight appears to get greater, until, when entirely out of the water, it has its original weight. It appears, then, that the upward pressure of the water on the body—what we call the *upthrust*—depends on how much of the brick is immersed.

If we repeat the experiment with a brick of same volume but different material, we find that the upthrust is the same as it was before. Hence the upthrust depends on the *volume* and hence the weight of the liquid displaced.

(*b*) The method used in this experiment is the usual one for finding the weight of a body in a liquid.

When the results of the experiment are examined we find that the upthrust and the weight of liquid displaced are practically equal. This conclusion is an extremely important

fact in science, viz. "*When a body is immersed in a liquid, either partially or totally,* (1) *the liquid exerts an upthrust on the body, and* (2) *this upthrust is equal to the weight of the liquid displaced by the body.*"

For example, if a lump of iron, whose volume is 10 c.c. and weight 72 gm., be immersed in water, it displaces its own volume, *i.e.* 10 c.c. of water, and hence 10 gm. of water. Thus the water exerts an upward push on it equal to 10 gm. It therefore seems to weigh only 62 gm. in water.

Note that the upthrust of a liquid on a body totally immersed depends on the *volume* and not on the weight of the body.

Historical. This law of nature we are discussing was discovered by *Archimedes*, and is referred to as the *Principle of Archimedes.* You will remember the story of the golden crown, when the method of finding its volume occurred to him as he was taking a bath. There was more in the idea. As Archimedes entered the water not only did he observe the displaced water, but he found himself becoming lighter, being buoyed up by the water, and the thought struck him that there was some relation between this buoyancy, or loss of weight, and the volume of water displaced. In short, he discovered the law which is now named after him. So overjoyed was he, the story says, that he jumped out of his bath and ran through the streets of Syracuse to the King's palace, calling: "Eureka! Eureka!" (I have found it out! I have found it out!).

EXPERIMENT 56. (*a*) From this experiment we see that the wood when floating in water has apparently no weight; it seems to have lost its weight. We infer that *the upthrust on the body is equal to the whole weight of the body.*

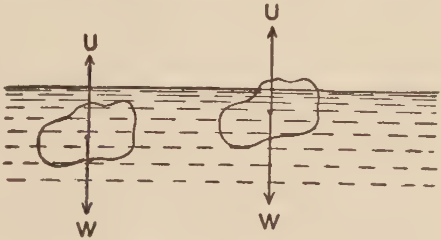
(*b*) We infer from this experiment that, no matter what the liquid may be, so long as the body is floating in it, its weight is equal to the upthrust. Thus the Principle of Archimedes is true also for a floating body. In this case the law is sometimes referred to as the *Law of Flotation*, and may be stated thus: "*A body which is floating in any liquid is displacing its own weight of that liquid.*"

For example, a boat weighing 10,000 tons displaces 10,000 tons of fresh water, or of salt water, if it floats in these liquids.

Conditions Determining whether a Body will Sink or Float in a Liquid

We are now in a position to understand why some bodies sink and others float in liquids; why a piece of iron sinks in water, for example, while an iron ship floats; and why it is easier to swim in the sea than in a river.

Let us consider a body, held either partially or totally immersed in a liquid, as in the diagram. In either position it is acted on by two forces —(1) the *weight* W, vertically downwards; and (2) the *upthrust* U of the liquid, vertically upwards. It is evident, then, that the relative values of W and U will determine whether the body will sink or float, if it be let go.



If W is greater than U, it will move in the direction of W, that is, it will sink farther into the liquid. If W is equal to U, it will remain steady, that is, it will neither sink nor rise in the liquid. If W be less than U, it will rise in the liquid until W and U are equal; remembering that U is equal to the weight of liquid displaced, we see that it will rise partly out of the liquid if already totally immersed, or farther out of the liquid if already partially immersed, until the part under the surface of the liquid is displacing an amount of the liquid equal in weight to that of the body.

Now if we take, say, a piece of plasticine, and hold it just touching the surface of water, and let it go, at the instant we let go it is acted on by its own weight (the force of gravity); it is not displacing any water, and so there is no upthrust on it. It therefore sinks into the water. As it sinks it displaces more and more water; therefore the upthrust becomes greater and greater, until it is completely under water, while its own weight remains the same as it was. When completely immersed it is displacing its own volume of water, but the density of the water is less than the density of the plasticine, therefore the weight of water displaced (the upthrust) is less than the weight of the plasticine; hence it sinks. We thus

see that a solid body, whose density is greater than that of the liquid, will sink in the liquid.

Now let us take the same piece of plasticine, that is, the same volume and the same weight, and mould it into the shape of a cup or a boat, and repeat the experiment. Hold it, with the bottom of the cup or boat just touching the water, and then let go. As it sinks into the water it displaces more and more water—*i.e.* the upthrust on it increases more and more. There comes a point when the body is displacing an amount of water equal to its own weight, that is, when the upthrust is equal to the weight of the body. Then it floats, and this happens long before the plasticine vessel is completely immersed, *i.e.* before the water reaches the rim of the cup.

We see, then, that a substance whose density is even greater than that of a liquid may be made to float in the liquid, if shaped accordingly. Thus, though iron is denser than water, and sinks itself in water, still an iron ship floats.

SECTION IX

MAGNETISM

Experiment 58. By touching various substances with a magnet it is found that iron and steel, and to a less extent the metals nickel and cobalt, are attracted, but most other substances are not. Thus iron, steel, nickel, and cobalt are said to be *magnetic* ; the other substances are *non-magnetic*.

If a magnet be dipped into iron filings they cling in clusters round the ends of the magnet, but not at all at the centre. The points near the ends towards which the filings are attracted are called the *poles* of the magnet (in the horse-shoe magnet the poles are brought near each other). The straight line joining the poles is the *magnetic axis*. An unmagnetised needle does not attract iron filings.

If the magnet be allowed to swing freely in a horizontal plane, it vibrates slowly, and finally comes to rest. If it again be set to swing, it will gradually come to rest with its axis pointing in the same direction as before. This direction is approximately *North and South*. It is called the *magnetic*

meridian—it is *magnetic North and South*—which direction makes an angle (called *declination*) with the geographical north and south. (This was discovered by Columbus.) Also the same pole of the magnet is always towards the north when the magnet comes to rest: it is therefore called the *North pole* (or, better, the *North-seeking* pole) of the magnet; the other pole is called the *South pole* (or *South-seeking* pole). Usually the North pole is marked with the letter "N," or simply with a line across the magnet. An unmagnetised needle does not come to rest in any particular direction.

If the poles of one magnet be brought near the poles of another magnet, it is found that (*a*) a north pole repels a north, but attracts a south; (*b*) a south pole repels a south, but attracts a north—*i.e.* "*Like poles repel, unlike poles attract.*"

Unmagnetised steel attracts either pole of a magnet, and either pole of a magnet attracts either end of unmagnetised steel.

Thus *repulsion is the only test of a magnet.*

The region round a magnet where its influence is felt is called the *magnetic field* of the magnet.

The fact that a magnet needle vibrates slowly when away from pieces of iron or other magnets, and comes to rest in a N.-S. direction, shows that the Earth is a large magnet, having poles. These are situated, the North Magnetic Pole in Boothia Felix, north of Canada, and the South Magnetic Pole in the Antarctic.

Historical. The name "magnet" is derived from an ancient city in Asia Minor, called Magnesia, for near it a mineral was originally found which had the properties we have just discovered are possessed by an *artificial magnet*, viz. it attracted iron, and when suspended and allowed to swing in a horizontal plane it came to rest in a certain direction. This mineral is called magnetite. On account of the second property it could be used to find directions, and therefore was a "leading" stone, or *lodestone*. A lodestone is thus a *natural magnet.*

Experiment 59. Magnetism may be destroyed by strongly heating a magnetised needle. By stroking a piece of steel one way with a permanent magnet, it becomes magnetised, and the end of the needle last touched becomes a pole of the opposite kind to the pole used for stroking; *e.g.* if an N-pole be used,

the end of the needle last touched by it becomes an S-pole, and *vice versa*. A piece of steel may be magnetised in the same way by stroking it with a natural magnet, *i.e.* the lodestone, though the magnetism is in this case weaker.

The same result is found after stroking by the second method.

You will learn later of a third method of magnetising a piece of steel, viz. by using an electric current. This is the method employed to make the permanent bar magnets you have been using.

N.B.—Iron, which differs in composition slightly from steel, is not used to make magnets. It is more easily magnetised than steel; we say it has a greater *susceptibility*. But steel keeps or retains its magnetism longer than iron; it has a greater *retentivity*.

When a piece of steel is magnetised there is no change in mass. Hence we infer that it has undergone only a physical change: it has simply acquired a new property: the substance is still steel. Of course, care must be taken to find the mass on a balance which has no iron and is removed from iron.

Magnetic Induction

Experiment 60. A piece of iron when in presence of a permanent magnet becomes magnetised. Magnetism is said to be *induced* in it, and the phenomenon is termed *magnetic induction*. The induced magnetism is only temporary—the iron loses its magnetism when the permanent magnet is removed. Remember iron is easily magnetised, but loses its magnetism also easily. Steel, on the other hand, would be difficult to magnetise by induction; but, on the other hand, it would remain magnetised after the inducing magnet had been removed.

The pole of the iron next the magnet has polarity opposite to the inducing pole, *i.e.* the pole next the iron, for, if the magnet is reversed, the poles of the iron are also reversed.

Not only can a permanent magnet induce magnetism in a piece of iron; but magnetism induced in one piece of iron can induce magnetism in another piece, the polarity of the latter obeying the same law as before. This is the reason why a string of nails or pen-points may be hung from a magnet. It also explains how iron is really attracted by a magnet. The magnet first of all induces magnetism in the iron, a north pole

inducing a south, and these, being unlike poles, attract each other. Thus the most important things to remember about induction are :

I. It is temporary.

II. The inducing pole induces a pole of the opposite kind next to it.

III. Magnetic induction always precedes attraction.

An iron rod, held sloping towards the north in the earth's field and tapped, becomes slightly magnetised. The earth's magnetism induces magnetism in the iron, and the upper end attracts the N-pole of a magnet needle.

PART III—APPLICATIONS

SECTION I

VOLUME—MASS—DENSITY

THE story is told of Charles II that he was wont to ask his courtiers the reason of the following: If a dead fish were put into a bowl full of water, some water overflowed; but if a live fish were put in, the water did not overflow. Can you explain? Remember Charles II was no scientist. It stands to reason that whether the fish were dead or alive, its body, being composed of matter, occupied space, and therefore would displace water in both cases.

If we are given a cup of tea accidentally filled to the brim, and we put in a teaspoon, we find that some of the tea is displaced.

It has frequently been asked whether Archimedes would have been led to his method of finding volume by displacement if he had taken his bath in a large expanse of water, say, the ocean, instead of in a small bath; for he would have been unable to see any rise in the level of the water.

The gram is a suitable mass for use in finding the mass of small bodies, but would be much too small for, say, finding the mass of a quantity of coal. So another unit is used, called the *Kilogram* (Kg.) (kilo is derived from a Greek word meaning 1000). A Kg. is thus 1000 gm. The standard kilogram is the mass of a lump of platinum kept in Paris, just as the pound (lb.) is the mass of a lump of platinum kept by the Board of Trade in London. 1 Kg. = 2·2 lb.: 1 lb. = 454 gm.

The fact that the least dense liquid rises to the top affords an explanation why cream collects on the surface of milk when it stands, the reason being that the cream is the least dense of the substances composing milk.

Substance is the term applied to the different kinds of

matter that compose bodies. For example, iron is the substance of which railings, pots, hinges, etc., are made. Different substances have different *densities*. So you will understand that the density of a substance is of great importance, as by finding it we may be able to identify the substance. For instance, if we have a clear, colourless, tasteless, odourless liquid whose density we find to be 1 gm. per c.c., it is certain to be water. Density is also of great importance in determining what substance should be used in the making of certain machines. In the manufacture of aeroplanes we should look for a metal having a low density, and hence the use of aluminium, whose density is only 2·58 gm. per c.c., that of most other metals being considerably higher.

Questions on Section I

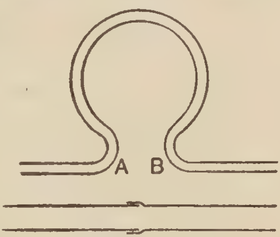
1. A bottle has a mass of 20 gm. when empty, 70 gm. when full of water, what is its capacity ?
2. If the same bottle has a mass of 60 gm. when filled with alcohol, what is the density of alcohol ?
3. What would be the mass of a litre of alcohol ?
4. Why does cream rise to the surface of milk ?
5. If the density of brass is 8·33 gm. per c.c., what is the volume of a 100-gram "weight" ?
6. When milk is 8d. a quart, what is the cost of a litre ?
7. How would you find the volume of a drop of water ?
8. How would you find the mass of a drop of water ?
9. Two pieces of metal have been painted—one is copper and one lead. Describe how you would find which was which ?
10. How would you find the volume of a sweet ? (Sugar is soluble in water.)
11. A bottle labelled "Alcohol" contains a liquid whose density is found to be ·89 gm. per c.c. What would you infer about its purity ?
12. If it took one boy to move a pail full of water, how many boys are required to move the same pail full of mercury ?
13. If a pint of water has a mass of $1\frac{1}{4}$ lb., what is the mass of a pint of mercury ?
14. Why are we generally advised to "shake well" a doctor's bottle ?

SECTION II

HEAT—EXPANSION—THERMOMETRY

Expansion of Solids

The fact that solids expand when heated and contract when cooled has many important, necessary, and interesting applications. In laying a railway, engineers leave a space between each length of rail to allow for expansion in warm weather. Otherwise, if no room was left for such expansion, the rails would be forced out of the straight position with serious consequences. The ribs of a fireplace must not be rigidly fixed if they are made straight; if fixed at the ends they are generally curved outwards, so that when heated they lengthen and curve further. Precautions must likewise be taken in iron-bridge building to allow for expansion and contraction; for example, the Britannia Tubular Bridge between Carnarvon and Anglesey has parts resting on rollers, which enable them to expand without straining. In factories where steam has to be carried long distances, the steam pipes are laid with a curious bend (see figure) every hundred or two hundred yards. The parts marked A, B may come closer or go further apart without breaking the pipe. Pipes are themselves joined telescopically (see figure).



If cold water be poured on thick hot glass some parts cool before others, so contract, and the strain breaks the glass. Similarly, if hot water be poured into a vessel of thick glass, the unequal expansion breaks the glass. This is the reason why science beakers are made of thin glass. If a glass stopper be firmly fixed in the neck of a bottle, it may be conveniently removed without forcing, and thus avoiding the danger of breaking the bottle, by wrapping a cloth soaked in hot water round the neck, so that the glass of the neck expands before the heat reaches the stopper, which may be simply lifted out.

When metals expand or contract, the great force exerted is made use of industrially. In fixing the iron plates of a ship or a boiler the rivets are put in red hot. As they cool and

contract they bind the plates firmly together and make the ship water-proof, or the boiler steam-proof. When a cartwright is putting on the iron tyre of a cart-wheel, it is made so that when hot it just slips over the wooden rim. As it cools it contracts and binds the wooden parts very firmly together, and also presses the spokes further into the hub.

If the wall of a building bulges, iron is passed through it to the other wall, and plates of metal are screwed up close to the walls on the outside. The rod is heated, and lengthens, and the plates are screwed up closer to the walls. As the rod cools it contracts and brings the bulging wall with it.

You have all watched how the telephone wires along the railway seem to rise and fall as you pass along in the train. This is due to the sagging of the wire between the poles, which is more pronounced during summer than during winter because of the expansion by heat. During a snowstorm the wires often snap, for two reasons : (1) the wires have contracted with the cold, and (2) the weight of the snow on the taut wires bears them down. The same thing applies to wire fences, which should not, therefore, be put up tight during summer.

In clamping glass apparatus (*e.g.* tubes and flasks) in the science room, it is important that they should not be held firmly if the apparatus has to be heated, because if the parts be too firmly clamped they are prevented from expanding with the parts free to expand, and hence the apparatus is very liable to break. Similarly, in fixing a glass globe to the gas light, we must not screw it on too tightly, but just tightly enough to be held ; it must be able to turn round in the socket. Globes made of a special patent material are now being used, whose expansion on being heated is so small that it is almost negligible for the temperatures at which it is used : in fact, it may be heated white-hot and cold water allowed to drop on it without its being even cracked.

When panes of glass, especially the large sheets of plate glass for shop windows, are fitted into the frames, they must not be rigidly fixed : the frames must be a little wider than the glass to allow for expansion with rise of temperature.

Another interesting fact is worth noting. The pitch of a violin string, and also of any string in a stringed instrument, depends on its tension, *i.e.* its "tightness." The tighter the string the higher is the note. Now the strings of a piano, which are made of metal, expand and contract with change of

temperature, and hence the pitch of the different notes is likely to vary. The piano should therefore be tuned at a temperature when it is most likely to be played.

Expansion of Liquids

The expansion of liquids under rise of temperature is made use of in the construction of mercury and alcohol thermometers. A kettle of water should not be filled to the brim, because, when put over the fire or gas burner, the liquid expands and overflows.

You get better value for your money if you buy milk when it is cold than when warm, because, if measured while warm, it contracts to less volume when it cools, and you generally buy it not by mass but by volume.

Expansion of Gases

If a soft rubber ball be placed near the fire the air inside expands and the ball becomes harder. Cycle or motor tyres should not be fully inflated in the morning during summer. They will expand with the heat during the day, and are then liable to burst. Similarly, if inflated hard in the middle of the day, they will become softer because of the contraction of the air when it cools. A football which has been inflated indoors, where it is comparatively warm, will likely become soft during play out of doors where it is cold.

Boiling

You have learned that when water is boiling it is not becoming any hotter: its temperature remains at the boiling point so long as there is any water. Hence, in cooking potatoes one small flame will be enough if the water is boiling; it is sheer waste to have two large flames, for, though the water may boil much more vigorously, it will be no hotter, and it is the temperature of the water, and not the rate at which the water is being boiled, that cooks the potatoes.

Steam Power

In Experiment 12 you no doubt observed the very large volume of steam that was issuing from the boiling water without a great diminution in the volume of the water during

the same time. This is an extremely important scientific fact. When water at 100° C. boils, the volume of the steam from it is about 1700 times the volume of the water converted to steam. Thus a cubic inch of water at the boiling point becomes nearly a cubic foot of steam. It is this great expansion which gives steam its great power and works steam engines. The steam from the water boiling in the boiler of the engine can escape in one way only, viz. by entering the cylinder (a cylindrical chamber), where its great expansion pushes a piston in front of it. The movement of the piston, to which is fixed a rod called the piston-rod, works levers, etc., which in turn act on the wheels.

This great expansion of water, when changed to steam, explains the rise and fall (the rattle) of the lid of a kettle when the water in it is boiling. The steam coming from the water in great volume forces up the lid ; some escapes, and the lid falls down again on to the kettle, to be raised once more by the steam, and so on.

It is thought also that volcanic eruptions are caused by the same fact. Water from the ocean may enter the interior of the Earth by fissures in the rocks, and is there converted rapidly by the heat into steam, the great expansion forcing rocks and solid matter to the surface. If you examine the map you will no doubt be struck by the fact that most volcanoes are near the coast.

Melting

Most known solids melt if their temperature be raised sufficiently. Even iron melts, and this enables the metal to be cast into almost any required shape. Iron grates, pots, pans, wheels, etc., are made by allowing the molten metal to flow into a mould of the required shape and size. On cooling, the iron solidifies into the shape of the mould. If wrought iron be heated red-hot it becomes more pliable and is fit to be hammered or "wrought," and the hotter it becomes the more easily is it worked.

Paraffin-wax candles are made by allowing the molten wax to flow into cylindrical moulds, in the centre of which is stretched the wick. On cooling, solid candles are formed. When a candle burns, the wax must first be converted into a vapour. The heat from the burning match first melts a little of the wax, and then the liquid wax is vaporised, and only

then does the candle burn. On nearing the melting point paraffin wax becomes plastic and soft. Frequently packets of candles become soft in the summer and are found sticking together in a solid mass.

Similarly, butter in warm weather is softer than in winter, because the temperature in summer approaches the melting point of butter.

In using sealing wax we make use of the peculiar properties of the substance. We melt it by holding it in a flame, allow the molten wax to drop on the place required, where it immediately solidifies again.

In the manufacture of certain explosives you will easily understand that the temperature of the buildings where they are made must not rise too high in case of fire. But there is also a certain temperature below which the buildings are not allowed to go, because of the danger of some of the explosive matter being solidified, and in this state it is very dangerous if allowed to get into machinery.

A spot of grease in cloth may be removed by putting a piece of blotting paper over it, and running a hot smoothing iron over the blotting paper. The heat of the iron melts the grease, and the molten substance is taken up by the paper in the same way as ink is.

Other substances can be heated to a very high temperature without being melted, that is, they have a very high melting point. Such are the metals used in the making of the fine filaments in electric light bulbs. They are heated by the electric current very highly and are not melted. Some of you have been at a "lime-light" lecture. It is so called because the lantern contains a "lime" light. An exceedingly hot flame is allowed to impinge on a cylinder of lime, and causes it to become so hot that it becomes white hot—*i.e.* incandescent, and the incandescence gives the brilliant light. It is possible to heat the lime so very highly without melting it.

Gas mantles are likewise made of a substance which is not easily melted. When introduced into the gas flame this substance (thoria) becomes incandescent with the heat.

Questions on Section II

1. Wire fences put up in summer should not be too tight. Why?
2. Why are the science beakers made of thin glass?

3. Why do photograph films curl up if laid on the hand ?

4. If a mercury-in-glass thermometer be plunged into hot water, there is a momentary fall in the level of the mercury. Explain.

5. Why is it dangerous to inflate motor tyres highly on a hot day ?

6. Define *melting point, boiling point, latent heat of ice, latent heat of steam.*

7. Distinguish *heat* and *temperature.*

8. Which is at the higher temperature, a pint or a gallon of boiling water ? Which could melt more ice ?

9. What makes a kettle lid rattle when the water is boiling ?

10. The temperature of the blood of a healthy person is 98·4° F. What is it on the Centigrade scale ?

11. The boiling point of alcohol is 78° C. What is it on the Fahrenheit scale ?

12. Why is sealing wax held in a flame before being used ?

13. Will eggs cook more quickly in water boiling vigorously over two Bunsen burners than just boiling over one Bunsen ?

14. Why has the thermometer tube such a narrow bore ?

15. A hot lamp chimney sometimes cracks if a cold draught of air blows against it. Why ?

16. Explain why butter is soft in summer and more solid in winter.

17. Draw a graph to convert temperatures from the Centigrade scale to the Fahrenheit scale, and *vice versa.*

18. On what scientific fact does the working of a steam engine depend ?

19. What advantages has (*a*) mercury, (*b*) alcohol in the thermometer ?

20. What is the use of (*a*) lime in the production of the "lime-light," (*b*) an incandescent gas mantle ?

SECTION III

SOLUTION—EVAPORATION—CRYSTALLISATION—DISTILLATION

You are already familiar with some common soluble substances used at home—salt, sugar, washing soda, soap, etc. ; and some common solvents—water, petrol, turpentine, methylated spirit, etc. The coffee and tea that you drink are really

solutions of part of the coffee bean and tea leaf in boiling water.

When bathing in the sea you have no doubt got an unpleasant mouthful of sea water, which contains a number of substances dissolved in it, mostly common salt. The sea is becoming more and more salt every year. In fact, from the rate at which it is getting dissolved matter, geologists have been trying to calculate how old the Earth is, and have come to the conclusion that its age is somewhere in the neighbourhood of 50 million years. And where does the salt come from? Rivers flowing over soluble material, and getting it from industrial towns, carry it down; the water of the sea itself is continually dissolving some from the rocks. The heat of the sun again is continually evaporating the water, which prevents the ocean from getting any fuller. At the same time the salt, which is not volatile, remains in the sea, and thus the ocean is becoming more and more salty.

Other liquids besides water are used as solvents. In some kinds of rubber solution used by motor mechanics and cyclists to repair punctures, the solution is made by dissolving rubber in an evil-smelling liquid called carbon disulphide. On spreading out the solution, the solvent evaporates into the air, and leaves the rubber in the solid state.

To remove grease stains from glass we rub with a cloth soaked in petrol or turpentine. These liquids dissolve the grease, and it is lifted away as a solution. Similarly the ivory keys of a piano may be cleaned by rubbing with methylated spirit. Petrol may be conveniently used also to remove stains from cloth: the petrol, being so volatile, rapidly evaporates. Again, varnishes are generally solutions of certain chemicals in spirit. If the spirit evaporates the varnish becomes "thick," and may therefore be "thinned" by adding more alcohol.

The volatility of paraffin oil is often made use of to keep a clock oiled. The paraffin is introduced into the bottom of the case of the clock by being soaked in a rag of cloth. The vapour rising penetrates into all parts of the clockwork, and thus keeps it well oiled.

Pure water may be got from sea water by distillation. Rain, which comes mostly from the sea, is really *distilled* from the ocean, and is thus the purest form of natural water. Tap water contains quite an appreciable quantity of dissolved

matter, depending on its source. Sea water contains much matter in solution. The formation of rain is an example of distillation on a large scale. The water is evaporated from the sea by the heat of the sun, and the vapour is condensed in the cold upper regions of the air—which correspond to the Liebig's condenser of the experiment—and falls to the earth as rain. If we blow our breath on a cold surface—say, the glass of a mirror—the mirror becomes dim. The vapour contained in the breath is condensed on the cold glass into small drops of water. The same thing occurs when we breathe on a frosty day—the cold air condenses the vapour and the small globules of water appear as a white cloud. In fact, that is how the large clouds in the sky are formed, the invisible vapour, in cooling, condenses to small globules of water.

Syrup is a very concentrated solution of sugar. If a tin of syrup be allowed to stand open in the air for a time, the water is continually evaporating. There comes a point, therefore, when the amount of sugar is more than necessary to saturate the solution, with the result that some of it crystallises out and we have the syrup becoming "sugary." Jam left exposed also becomes "sugary."

We have seen that the slower crystallisation takes place, the larger are the crystals. If a dense sugar solution be left to cool slowly we get large crystals called "barley sugar," the crystallisation is assisted by hanging a thread with a small crystal into the solution.

In evaporating liquids we use wide and shallow vessels, for the larger the area exposed the more rapid is the evaporation. Now we shall learn later that when liquids do evaporate they use up heat, and hence become cold. We do not wish our tea to become cold, and therefore try to prevent a rapid evaporation. Our tea-cups are therefore made deep and narrow, for we take time over the drinking. But in taking soup we do not wish the soup to last as long as, say, a cup of tea, and hence we have no desire to keep it hot, so we eat soup from a plate, which is wide and shallow.

To prevent liquids from evaporating we keep them in bottles, and stopper the bottles. Thus ink remains liquid in a bottle, but if it be spilled it soon dries up—the liquid part goes into the air in the form of vapour.

This is how paste, glue, and gum are used. These are solutions; when exposed to the air—that is, when spread out—

the water evaporates, leaving the solid matter behind as a hard mass holding bodies together.

Wet clothes are not dried by folding them and putting them in a drawer. They are hung out in the open and spread so that as large a surface as possible is exposed, to hasten the evaporation of the water. Or they are hung before a fire—the higher the temperature, remember, the greater the evaporation.

In connection with crystallisation, it is interesting to note that diamonds may be made artificially from a hot solution. Diamonds are composed of the element carbon in a very hard crystalline form ; it does not resemble in the least the charcoal you see used for drawing, but it is composed of the same substance. Now carbon may be dissolved in molten iron at a very high temperature. If this solution be suddenly cooled by being plunged into cold water, the iron on the outside is solidified, while it remains liquid in the inside. This solid crust causes a great pressure on the solution in the inside, and when all the iron has been solidified and cooled, small diamonds are found in it—the charcoal has been made into a clear crystalline form. This would suggest that natural diamonds have been formed in the earth by carbon crystallising from a hot solution under the very great pressures which must exist in the interior of the Earth.

Questions on Section III

1. Define *solution, solvent, solute, saturated solution, crystalline, solubility*.
2. Ink dries up when spilt on the table, but when kept in a bottle it does not dry up. Explain the difference.
3. Water is continually flowing from the River Jordan into the Dead Sea, which has no connection with the ocean. Why is the Dead Sea not becoming fuller ?
4. A cloth soaked in paraffin and put into the case of a clock keeps it oiled. How ?
5. How can petrol take grease stains out of cloth ?
6. How could you get pure water from sea water ?
7. Define *filtrate, distillate, condensation, fractional crystallisation*.
8. Why does glass become dim when you breathe on it ?
9. Why does jam become "sugary" when it has been left open to the air for some time ?
10. What processes would you employ to separate sugar from sand ?

11. Why does gum become dry when spread over a label ?

12. Describe how you would get large crystals of alum from powdered alum.

13. Why do you see your " breath " on a cold day and not on a warm day ?

14. Which of the following waters contains (1) most, (2) least matter dissolved in it, and why—(*a*) sea water, (*b*) tap water, (*c*) rain water ?

15. How would you test whether (1) a solid, (2) a liquid, were pure ?

SECTION IV

THE CHEMISTRY OF THE AIR—RUSTING—BURNING

Physical and Chemical Change

We have already in the preceding sections studied many changes which are purely *physical*, that is, changes only in the properties of substances where the substances themselves remain the same. When ice and paraffin wax melt, the substances are still the same as before melting : they have only changed their state. Similarly the changes from water to ice, or liquid paraffin to solid paraffin, are physical changes, as are also the changes of water to steam and steam to water. When salt is dissolved in water, the salt is simply changed into the liquid state ; we still have salt and water. On evaporating the solution, we still have the same two substances—the salt back again in its solid form, while the liquid water is now in the form of vapour. And so with filtration, distillation, and crystallisation—all these are physical processes.

But when iron rusts we have a *chemical* change, a change in the substance. There are many chemical changes with which we have long been familiar. By far the most important from our point of view are breathing and digestion. When coal, wood, paper, oils, coal gas, etc., burn, we have another extremely important chemical change taking place, the substances taking part in them being entirely changed, because what is left is no longer coal, wood, oil, or coal gas.

In toasting a piece of bread, and in baking and cooking, we have further examples of chemical change. A boiled

potato has a different taste from a raw one, because the substance in the raw potato has been changed into a different substance by the cooking.

Bricks are made by baking certain kinds of clay in hot ovens, and we cannot get the clay back again from the bricks. The brick is made of an entirely different substance from the clay: the baking has produced a chemical change. Similarly, in the making of porcelain from china clay, we have a corresponding chemical change.

Rusting

We have seen how iron is easily rusted when exposed to moisture and the air, and that iron rust is very brittle. Hence such a useful metal as iron, from which are made bridges, railings, utensils, etc., must be prevented from rusting: it must be protected from the rain and the air. This is attained by various methods. Bridges and railings are painted, the film of paint keeping the air and the rain from getting at and rusting the iron. The corrugated iron we are all familiar with in the roofs of outhouses and huts is simply sheet iron coated by a certain process with zinc—it is called "*galvanised*" *iron*. Zinc is not so easily rusted as iron. "Tin" cans are not really made of tin (tin is too expensive a metal), but of sheet iron which has been dipped in molten tin and gets a coating of this metal. "*Tinned*" cans would, therefore, be a better name for them. If a scratch be made on the tin so as to remove a little of it and expose the iron, the latter rusts where the scratch is made. Certain parts of cycles, and cooking utensils which are made of iron, are enamelled, *i.e.* coated with a thin layer of glassy substance; other parts or vessels are *nickel-plated* or electro-plated, *i.e.* have a coating of a metal which is not easily rusted. This is done by a special electrical process. The metal rims of bicycles, steel skates, tools, etc., are often smeared with vaseline before being put away for a season.

Roasting of Metals

We have all seen the sparks fly from a blacksmith's anvil, and also the great quantity of blue-black scaly material scattered over the smithy floor. What do the sparks and this blue-black material consist of? When the iron is red-hot it combines with the oxygen or "active" gas of the air, forming

iron calx which, like other calces, is brittle ; so when the smith brings down his hammer, the calx, still red-hot, is broken off and flies around. When it cools it is blue-black in colour. Notice it is a different compound from iron rust, which is red.

The filament of an electric glow lamp is made of very thin metal wire. When a current of electricity passes through it, it becomes very hot. If there were any oxygen in the bulb it would form a calx, *i.e.* a powder, and hence the filament would be destroyed. The glass bulbs are therefore made with no air in them, or filled with a gas which (like nitrogen) does not combine with the metal to form a calx. A wireless valve is, for the same reason, made a vacuum, *i.e.* devoid of gas. The iron wire gauze we use in the science room to spread the flame of the Bunsen burner becomes so brittle that holes are easily made in it. The hot metal combines with the oxygen of the air, forming a brittle compound.

Polished steel parts of a grate in which is burning a hot fire become tarnished—they appear blue-black—due to a thin film of iron oxide formed in the same way.

Questions on Section IV

1. Define *chemical change, drying agent, combination, decomposition, element, compound.*

2. Why are iron railings and bridges painted ?

3. Which of the following are physical and which chemical changes—(*a*) the melting of paraffin wax ; (*b*) the rusting of iron ; (*c*) the toasting of bread ; (*d*) solution of sugar in tea ; (*e*) distillation of sea water ; (*f*) burning of coal gas ?

4. Why does a poker when withdrawn from a red-hot fire appear blue-black, though it was brightly polished before being put in ?

5. What is meant by a Law in Science ? What is meant by saying that "matter cannot be destroyed" ? Describe an experiment to illustrate.

6. Describe an experiment in which you could find the composition of the air.

7. Phosphorus is burned in a tightly corked flask of air ; if the capacity of the flask be 1 litre, how much water will enter the flask if it is opened under water ?

8. How could you prepare oxygen from the air ? How would you prepare nitrogen from the air ?

9. Give an account of Lavoisier's famous experiment by which he explained the meaning of burning.

10. How would you show that iron rust contains oxygen ?

11. Describe, with sketches, an experiment to show the changes

which occur when phosphorus fumes in an enclosed space of air above water. What does the experiment prove about the composition of air ?

12. Describe the changes that take place when mercury calx is heated first gently and then more strongly.

13. What is meant by saying that "compounds have a constant composition" ?

14. How many lb. of mercury could be got from 50 lb. mercury calx ?

15. How do you explain the fact that iron rust, a red powder, contains a colourless gas, oxygen, and a dark grey metal, iron ?

16. Why are wireless valves made without any air in them ?

SECTION V

THE CHEMISTRY OF THE AIR—OXYGEN—NITROGEN

Properties of Oxygen—Burning

The fact that oxygen is soluble in water to an appreciable extent serves a very useful purpose in Nature. It is the oxygen dissolved in the water of rivers, lakes, and the ocean that enables fishes to live. They pass the water through their gills and thus extract the gas. In an aquarium, that is a place where live fish are kept, the water is kept fresh by a constant stream running through the tanks. It has been observed that the fish keep close to the spot where the water enters—thus getting the better supply of the oxygen.

We have learned that burning is simply oxidation, and that if no oxygen is present the burning ceases. We blow a badly burning coal fire with bellows, for we increase the supply of oxygen, and thus hasten the oxidation. If we burn a book or a roll of paper, the air and therefore the oxygen cannot get into the inside leaves, which are packed closely together, and hence only the edges are burned, since burning is oxidation.

Breathing is also oxidation. We take into our lungs air , the oxygen is used up to oxidise the waste matter in the body, and thus oxidation, which is chemical combination (and

therefore an exothermic action), generates the heat which makes our bodies warm. We breathe out the oxides, along with the nitrogen which we do not use. This was the reason why the explorers who attempted to climb Mount Everest a few years ago kept themselves warm by breathing oxygen (instead of air), though the oxygen was cold ; it increased the rate of oxidation, and therefore the supply of heat.

If a person's clothes catch fire it is better for him to wrap an overcoat or a blanket round him, or to roll on the floor, and thus prevent the oxidation by excluding the oxygen. By running outside he would simply be increasing the supply of oxygen, and therefore the combustion.

This is just what is meant when we read that during a fire the wind "fanned the flames." The current of air we call a wind brought a more rapid supply of oxygen.

Some things catch fire more easily than others. Substances have to be raised to a certain temperature (called their *ignition temperature*) before oxidation commences. Thus phosphorus, which catches fire easily, has a low ignition point ; it has a great *chemical affinity* for oxygen. In kindling a fire, we first of all light a match by rubbing the "head" on a rough or prepared surface. The friction raises the temperature to the ignition point of the substance forming the head—it is comparatively low. As the head burns it vaporises some of the substance composing the wood of the match, and these then catch fire. On applying the lighted match to the paper with which the fire is laid, it catches fire easily. The ignition point of the wood is higher, but the heat of the burning paper soon vaporises the substances composing it and raises the temperature to the ignition temperature, and the wood in turn burns. Similarly the heat from the burning wood causes decomposition of the coal, and the products of decomposition next catch fire.

The flame we see during combustion is simply a region where the oxidation is taking place so rapidly that the heat generated is so great as to cause the vapours to glow. Sometimes the luminosity of the flame is due to solid particles in the region being so hot that they are incandescent. That is how the light of an incandescent gas mantle is produced.

We poke a badly burning fire to hasten the burning. By poking we generally lift up a piece of coal, or clear away the ashes. This allows air and therefore oxygen to enter more easily. Thus the burning, which is oxidation, is increased.

Acids and Alkalies

Acids and alkalies play a great part in everyday life. Acids were originally recognised by their sour taste—hence the name *acid* (Latin: *acidus*=sour). They were mostly derived from plants, some from minerals. The former were therefore called *organic* acids, the latter *mineral* or *inorganic* acids. The acid in lemon and orange juice, which gives these fruits their sour taste, is citric acid. Oxalic acid (which is poisonous) is found in wood sorrel; malic acid in apples (Latin: *malum*); tartaric acid in grapes; formic acid in the stings of nettles and ants (Latin: *formica*=an ant). Vinegar is found naturally in wood, but may be derived from sour wine; lactic acid is got in sour milk. Boracic acid and rhubarb juice are well known. The commoner mineral acids are nitric, sulphuric, and hydrochloric. These are used extensively in chemistry. Nitric acid was formerly known as "aqua fortis" (Latin: strong water); sulphuric acid as "oil of vitriol"; hydrochloric acid as muriatic acid or "spirit of salt."

Among common alkalies may be mentioned washing soda, caustic soda, ammonia, magnesia, lime water, baking soda.

Sugar and salt are neutral.

It is interesting to test how many of the substances we constantly use are acidic, how many alkaline, and how many neutral. This can be done by dipping a clean glass rod into the solution, withdrawing it, and allowing the adhering drop to fall on pieces of red and blue litmus paper. Take pieces of litmus and test as many substances as you can.

We have seen in Parts I and II that, if we add sufficient alkali to acid, or acid to alkali, we neutralise them—that is, we produce a substance which is neither acid nor alkaline. If we experience that burning sensation known as "heart-burn" after eating fruit, we may be sure it is caused by an excess of acid in the stomach. It would therefore be remedied by taking a suitable alkali like magnesia, or lime water, or baking soda. (Magnesia, by the way, is another name for magnesium oxide, a basic oxide.)

Some acids are "stronger" than others, *e.g.* they destroy cloth. This is the case of the three mineral acids mentioned above; but the organic acids are generally weak acids. Though they may have a very sour taste, they do not affect cloth. Hence, if any acid is accidentally spilled on your clothing, you must immediately add water to the spot,

followed by ammonia solution, which will neutralise the acid before it has time to destroy the fabric. If too late, the acid will have done its mischief. Similarly, some alkalies, like caustic soda and caustic potash, have destructive effect on cloth too. Their action may be neutralised by diluted acid. But in either case we must use weak alkali like ammonia to neutralise the acid, or weak acid to neutralise the alkali, so that, if more is added than is necessary to neutralise it, it will be too weak to do any harm.

In baking scones or cakes, we use frequently sour milk and cream of tartar (acid) or tartaric acid, and still the scone does not have a sour taste. The acid is there to neutralise the baking soda to make the dough rise. (We shall learn later how the scone dough rises.)

Gases in the Air

Besides nitrogen and oxygen the air contains small quantities of other gases. Rain is water which comes out of the air. Hence the air must contain water vapour. Also, since coal, wood, paper, etc., contain carbon, when these substances burn, oxide of carbon (called carbonic acid gas) is formed. This is a gas and goes into the air, hence air contains carbonic acid gas in small quantities.

Over a hundred years ago an English scientist, the Hon. Henry Cavendish, found that after removing the oxygen, water vapour, and carbonic acid gas from a large quantity of air, the nitrogen that was left was denser than pure nitrogen got from a compound. Nobody seemed to be concerned about this until near the close of the nineteenth century, when another famous scientist, Lord Rayleigh, drew the attention of Sir William Ramsay to the fact discovered by Cavendish, and these two chemists set themselves to find out the reason. After a long series of very delicate and intricate experiments they found that there were very minute quantities of denser gases present in the air which accounted for the greater density of the "nitrogen." The reason why these gases were not discovered sooner was that they existed in so excessively small quantities, and, what is more important, form no compounds with other elements. They are *argon* (Greek: the lazy one), *neon* (new), *krypton* (hidden), *xenon* (stranger), and *helium.* The last-named was so called because it was found to exist in the sun, during an eclipse in 1868, by a special

process which you will perhaps be able to understand some day. (Greek: *helios* means the sun.) These five gases—all elements—called the "minor gases" of the air, compose only about 1 per cent. of its volume.

Questions on Section V

1. Describe what happens when the following substances are heated—(*a*) potassium chlorate, (*b*) manganese dioxide, (*c*) a mixture of these two substances.

2. Describe how you would prepare and collect jars of oxygen.

3. What is an *oxide*? Into what two classes are they divided? How are they distinguished?

4. Into what classes may elements be divided? How are they distinguished—(*a*) physically, (*b*) chemically?

5. Explain, with examples to illustrate, the meaning of the following terms: (*a*) *effervescence*, (*b*) *catalyst*, (*c*) *supporter of combustion*, (*d*) *exothermic*.

6. Which of the following substances are oxides, and which are not?—Give reasons.—Potassium chlorate, manganese dioxide, air, mercury calx, iron rust, magnesia.

7. What is the real meaning of "burning"? Why does a coal fire give heat?

8. If you try to burn a book you find it burnt only at the edges. Explain.

9. Why are lemons, oranges, rhubarb sour? How could you show the reason without tasting?

10. If you got acid on your clothes what would you do, and why?

11. Is air a mixture or a compound? Give reasons.

12. Mention four ways in which you could deprive a quantity of air of its oxygen and prepare nitrogen. Is the nitrogen thus prepared pure nitrogen? If not, what other gases may it contain?

13. Lavoisier, Priestley, Scheele, Ramsay—why is each of these names famous in the history of the chemistry of the air?

14. What mass of potassium chlorate would you require to heat to get 3·92 grams of oxygen?

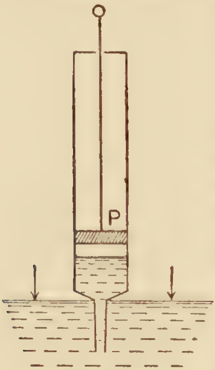
15. Fifty grams potassium chlorate and 20 grams manganese dioxide are heated to prepare oxygen. What mass of oxygen could be got? What does the residue consist of? What is the mass of each component in the residue? How would you separate the components?

SECTION VI

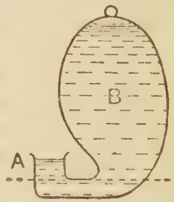
THE PHYSICS OF THE AIR—PRESSURE

THE PRESSURE OF THE AIR

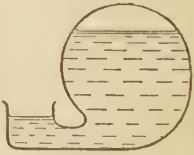
THE pressure of the air is made use of in various appliances. The figure shows the common syringe. The piston P is pushed down to the bottom of the cylinder, and the nozzle dipped into water. The piston is then drawn up while the nozzle is still dipping into the water. The water is forced up into the cylinder by the air pressing down on the surface of the water. The syringe is then lifted with the piston still drawn up, and the water remains in the cylinder, being kept there by the upward pressure of the air. If the piston be now depressed, while the syringe be held in any desired direction, the water is forced out through the nozzle.



The same process takes place in the use of the familiar fountain-pen filler, which consists of a short piece of glass tubing drawn out to a point, with a small rubber bulb on the other end. By squeezing the bulb some of the air is forced out and the pointed end dipped into the ink. On releasing the pressure, the bulb goes back to its former shape, thus diminishing the pressure of the air inside, while the pressure of the air on the surface of the ink, remaining the same, forces the ink up into the tube.



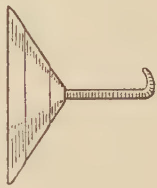
A glass drinking trough for birds is sometimes made as shown in the diagram. It is first of all completely filled with water. The air pressing down on the surface of the water in the open part A keeps the water in the larger part B, the reservoir. As the birds drink out of A, the level of the water gradually falls in A, until it gets below the level shown by the dotted line, when air enters B, and pressing on the surface of the water in B forces more water down



into A. Thus there is always water in A as long as there is any in B.

Pneumatic ink wells are made on exactly the same principle (see figure).

The parachute is like a large umbrella, made use of by aeronauts in making a descent from a high altitude from a balloon or an aeroplane. It hangs limp at first, like the closed umbrella, but is made to open by the upward pressure of the air, and the great surface it exposes to the air prevents it from falling too rapidly. It is kept upright by having a small hole in the centre of the top through which the air gradually escapes.



Jewellers sometimes use little rubber cones to exhibit their wares in the windows. By wetting them and pressing them against the smooth glass of the window the air in them is forced out, and the great pressure of the air keeps them sticking to the glass, like the boy's sucker, and such things as watches may be safely hung on them from the hook.

A pipette is a glass tube for transferring an exact volume of liquid from one vessel to another. One end is dipped into the liquid, and some air is sucked out of the tube, thus lessening the pressure of the air inside. The air pressing down on the surface of the liquid outside the pipette forces it up into the tube. By sucking sufficiently it is made to rise above a mark on the stem, the top end being then closed by the finger, which controls the flow of liquid until the level is at the mark. On pressing the finger tightly, the pipette is lifted out of the liquid with liquid in it up to the mark.

A straw may be used for sucking up water from a spring of water if a drinking cup is not available.

The Greatness of the Air Pressure

It may be asked why we are not crushed by the enormous pressure of the air. The reason is, of course, that there is as great a pressure inside pushing outwards as outside pushing inwards; and the pressure of the blood acts outwards.

When we try to drink out of a narrow-mouthed bottle, say, of soda water, the tongue sometimes sticks to the mouth of the bottle, or is drawn into it. The reason is that when some of the liquid flows out the pressure of the air that has got inside

is lessened, and the great pressure of the air outside forces the tongue into the mouth of the bottle, if it is in the way.

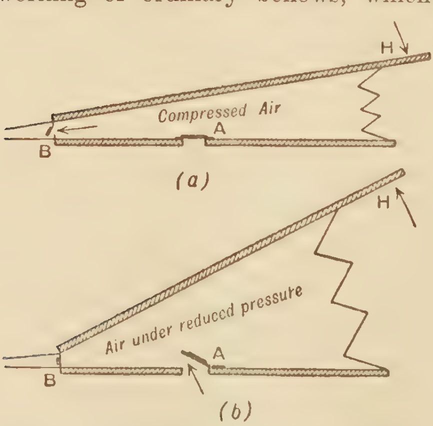
Water does not flow smoothly out of a bottle, but " gurgles " out, because the first quantity of water getting out lessens the pressure inside, and the air outside forcing its way inwards past the water forms bubbles, the making of which produces the noise we called " gurgling."

Break the point of an old electric light bulb under water, and the air presses water into the bulb to fill it. The bulbs are made exhausted of air, and the pressure of the air forces the water into the empty space. The bulb may now be lifted out, and the water remains in. The air pressure upwards keeps it, and the hole is too small to let the air even gurgle up.

In opening a tin of condensed milk it is necessary to make two holes at least in the lid, if an opener is not available to open it all round. If there were only one hole made the air pressure prevents the liquid from flowing out. If another hole be made the air presses in through one, and the weight of the liquid causes it to flow out by the other, the upward and the downward pressures of the air balancing each other.

Compressibility and Elasticity of the Air

The fact that air may be compressed is made use of in the working of ordinary bellows, which are used at home to " blow up " a badly burning fire, or by the blacksmith in blowing his furnace. Fig. *a* is a section of the bellows with the upper movable part H being pushed down. The air inside is thus compressed, and a flap A, which opens inwards, acting as a valve, is forced shut against the wooden part AB. Another valve or flap B, near the nozzle, opens outwards, thus the compressed air forces it open and the air rushes out at the nozzle. On drawing the handle H upwards

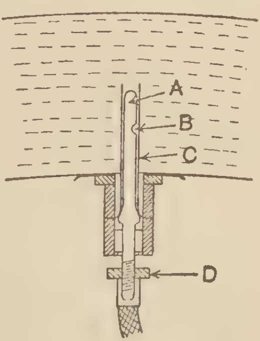


as in fig. *b* the pressure inside is released, and thus the air outside, being at a higher pressure, forces shut the valve B, while the valve A is forced open by air pressure inwards, and thus air enters the bellows; and the process is repeated, air entering by A and being forced out at B.

The elasticity of the air is made use of in many appliances in everyday use. A football or a tennis ball bounces, because when struck the volume of the air inside is diminished for an instant, and the air compressed; on trying to regain its former volume and shape—the rubber, of course, as well as the air being elastic, and the foot or the racquet having a greater inertia—the ball moves. (By inertia we mean the tendency matter has to continue in its present state of rest or motion.) If the ball has a hole in it, the compressed air is expelled through the hole, and thus the ball does not bounce at all, or if it does, just a little.

The use of pneumatic cycle and motor tyres depends on the elasticity of the air. On going over any obstruction in the shape of a stone, say, the tyre and the air inside yield a little, *i.e.* are compressed, and there is no harsh jolting as would be the case if the tyre were made of, say, wood, or some other inelastic substance. The compressed air then regains its original volume, and its "spring" absorbs the shock as it were. Air-filled cushions, depending for their comfort on the same property, make motoring even more enjoyable.

Most boys and girls have inflated a tyre with a cycle pump, and should understand the principle of the valve. The diagram shows its construction simply. A is a little metal tube, closed at one end, and having a small hole B in the side, over which is pushed a tightly fitting rubber tube C, which projects into the tyre (shown shaded). The end of the tube D from the inflater is screwed on the head of the valve AC. On pushing down the piston in the pump the air is compressed and forced into the tyre through the small hole B and the rubber tube C. When the piston is drawn up, the pressure of the air in the tyre, being now greater than the pressure of the air in the pump, presses against the rubber tube, thus



closing the small hole so that no air escapes from the tyre. More air is forced in and the tyre becomes filled with air, *i.e.* inflated. The greater the pressure becomes in the tyre, the more firmly is the rubber pressed against the small hole.

A device for closing doors gently depends on the fact that air is compressible. When the door is opened and then swings back to close, a plunger fitting into a cylinder of air is pushed in, and the air, acting as a buffer, is compressed, thus preventing the door from slamming. But the air is allowed to escape slowly, and thus the plunger moves slowly along the cylinder, and the door closes gently.

Buffers at railway stations are built on the same principle, and the recoil of the barrel of a big gun is taken up by a plunger or piston in a chamber containing air, which acts as a cushion.

Compressed air is used to force water out of tanks in submarines when they are required to rise to the surface of the water.

Various kinds of tools are constructed, whose use depends on the force exerted by compressed air—pneumatic drills, hammers, etc.

Experiment 45 enables us to understand the working of a soda-water siphon. In the course of manufacture of the aerated water, gas is forced by compression into the water, in which it dissolves. In the siphon, therefore, the gas above the liquid is compressed. On opening the tap the pressure of this gas forces the liquid up the tube.

Questions on Section VI

1. Why does water "gurgle" when you attempt to pour it out of a flask? Would it "gurgle" if there were a hole in the flask? Why?

2. If you push a tumbler inverted down into water, why does the water not rise inside the tumbler?

3. If a bottle, filled with water, be inverted mouth downwards into a basin of water, the water will not flow out. Why?

4. What is the purpose of the little hole at the top of the milkman's barrel?

5. Explain the action of—(*a*) the garden syringe; (*b*) the suction pump; (*c*) the cycle pump; (*d*) the valve of a cycle tyre; (*e*) the pneumatic ink well; (*f*) the bouncing of a football; (*g*) the parachute.

6. If water be boiled in a flask, and the mouth corked with a piece of banana, and allowed to cool, the banana cork is pushed right into the flask. Why ?
7. When the piston of a cycle pump is pushed half-way down, what is the extent of the compression ?
8. What did Boyle mean by the "spring of the air" ?
9. What is the real meaning of "suction" ?
10. Explain the use of the blacksmith's bellows and its working.

SECTION VII

PHYSICS OF LIQUIDS AND GASES—PRESSURE

THE SURFACE OF A LIQUID AT REST IS HORIZONTAL

LET us suppose we have a liquid in a vessel, with the surface AB not horizontal, as in the figure. Let P_1, P_2 be two points in the liquid at the same level. The pressure at P_1 is measured by the weight of liquid of height P_1Q_1, and pressure at P_2 by P_2Q_2. P_1Q_1 is greater than P_2Q_2, hence we have two different pressures at points on the same level. Therefore the liquid will move from position of greater pressure to position of less, until the pressures are equal, *i.e.* until the surface is horizontal.

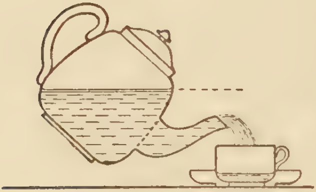
The surface of a liquid at rest in a vessel appears plane, but it is really only part of a much larger curved surface—the shape of the surface of the ocean.

WATER SEEKS ITS OWN LEVEL

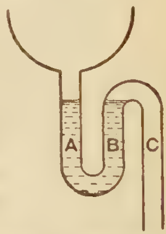
It is on account of this fact that water in a teapot or a kettle rises to the same height in the spout as in the vessel itself. It is obvious, therefore, that the spout must reach to the height of the lid, if it has to hold a good supply.

The same principle also enables us to pour liquid from vessels. If the pot be tilted towards the spout as in the

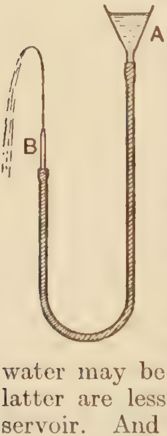
diagram, the surface of the tea remains horizontal. There is therefore a head of liquid between the mouth of the spout and the level of the liquid in the vessel, with the result that the difference of pressures causes the liquid to move and the tea flows out of the spout.



Perhaps you have noticed the pipe with the curious double bend underneath the sink (see diagram), by which the waste water runs off. It is so made that there is always water lying in it as shown. This serves as a trap to prevent any disagreeable odours from coming up from the drains. As the waste water is allowed to run away into the part A, it causes a difference of pressures, and the water rises in B, and so overflows into C; but there is never less water in the bend than is shown.



The water supply of a town is got from a lake or reservoir among the hills, whose level is above that of the highest buildings in the town. This may be illustrated by attaching a funnel (A) to a long piece of rubber tubing, carrying at the other end a piece of glass tubing with a small orifice (B). If the tube be bent in the form of a U the water tends to reach the same level in both limbs. If A be higher than B, there is a head of liquid between them, and the difference of pressures forces the water out at B. The greater the difference, the higher will the water be forced out of B, forming a fountain. If B be higher than A the water will not reach B. A represents the reservoir, and the tubes the pipes to the town, so that the water may be led across valleys and up hills, provided the latter are less high than the level of the water in the reservoir. And so long as the highest building is below this level, then the water will reach it. If a tap be turned

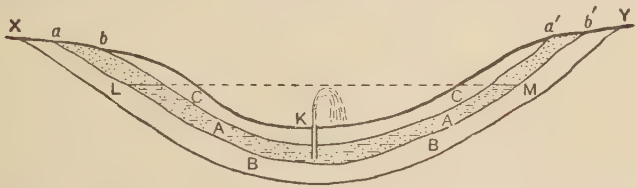


or opened in the building the water will immediately flow: we can illustrate this by pinching the rubber to resemble the tap.

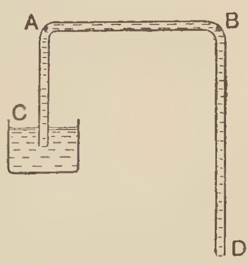
If, however, a building be higher than the water level in the reservoir then the water must be forced up by means of a force pump.

Artesian Wells

The figure represents a section of the earth's crust with various strata. AA is a stratum composed of porous rock or



broken material like sand, between two strata BB, CC, composed of rock or material through which water cannot penetrate, all these forming a saucer-like valley. The thick line XY denotes the surface of the earth, so that the stratum AA appears on the surface at "*ab*" and "*a′b′*," with possibly loose soil above. Rain falling on these areas *ab*, *a′b′*, penetrates into AA, and accumulates in the lowest part, say to height LM, between the impervious strata BB, CC, so that this level is above the level of the surface at some point K near the bottom of the valley. If a well be sunk at K down through CC there will be a head of water at this point, and water is forced up forming a fountain, or well of water. Such a well is called an Artesian Well, from Artois, a district of France, where such wells are numerous.



The Siphon

If we have a tube bent as in the figure—with one limb longer than the other—fill the whole tube with water and plunge the short limb into water in a basin, then water will flow from the basin through the tube, so long as the bottom of the long limb is under the level of the water in the basin. Let A and B be two

points on same level in positions shown; let C be a point on surface of liquid in basin, D the open end of the tube. Then pressure at A equals pressure at C less weight of column AC, and therefore atmospheric less weight of AC. Also pressure at B is atmospheric less weight of BD. But since AC is less than BD, then pressure at A is greater than pressure at B. Hence we have two different pressures at points on same level. Therefore the liquid moves from A to B.

Such an apparatus is called a *siphon*. A siphon is sometimes used in mines for draining water out of a section, over a higher partition into a lower section.

The Barometer and Height above Sea Level

The height of the barometer depends on the pressure of the air, which in turn depends on the height of the atmosphere. Hence if we ascend there is less air above us, and consequently the pressure becomes less. This was first demonstrated shortly after Torricelli had made the barometer. A celebrated Frenchman, Pascal, in 1648, had two barometers made at the foot of a mountain. One he caused to be left at the foot, the other was set up again at the top of the mountain, when it was found that the height of the barometer was less by about 8 cm. This suggests a method of measuring approximately the height of a mountain or an airship or aeroplane. It has been found that for the first 900 ft. we ascend above sea level the barometer falls 1 in. For the next 900 ft. it does not fall so much, because the higher we go the less dense the air becomes, and the less, therefore, is the pressure due to 900 ft. of it. Aeroplanes carry barometers for the purpose of recording the height reached. They do not, for obvious reasons, carry an ordinary mercury barometer, but an *aneroid barometer*.

In the same way, by descending a mine the pressure increases, and hence the barometer rises: by measuring the rise we can measure approximately the depth reached.

The Aneroid Barometer

This is a barometer constructed without liquid (Greek: *a*=without, *neros*=wet), and is an extremely delicate instrument. Its essential part is a metal cylinder partially exhausted of air, the top of which consists of a corrugated metal disc, which moves under a very slight change of pressure

due to the atmosphere. This movement is communicated by means of levers to a hand which indicates on a dial the pressure of the air. Aneroids used in determining heights have often the dial graduated to read heights in feet above sea level, instead of the corresponding pressures.

Weather Forecasting

In and around this country simultaneous readings are made of the barometer over a large area and sent to the Meteorological Office. These readings are plotted on the map, and lines (called *isobars*) are drawn through places having the same barometric pressure. In this way it is seen at a glance in which direction winds are likely to blow, and whether they will be high winds or only light breezes ; for the movement of the air which we call the wind will be from a region of high pressure to a region of low pressure, and the greater the difference of pressures between places near each other, then the more rapid will be the movement of the air, *i.e.* the stronger will be the wind.

Sometimes we see on the map a ridge of high pressure surrounding an area of low pressure. Such a system is called a *cyclone*. We then have the wind blowing inwards towards the low-pressure region, but, owing to the rotation of the earth itself, it tends to blow *round* as well as *towards* this area. It is obvious that if there is a current of air from all round towards this centre, there must be here an upward current into the cold regions of the air above, which has the effect of condensing the water vapour generally found where the pressure is low, and it falls as rain. Hence an area over which a cyclone passes generally has dull weather and rain. This we can predict from the map containing the isobars.

A region of high pressure surrounded by one of low pressure is called an *anticyclone*, and here we have the opposite conditions, viz. dry and sunny weather. (The reason can be followed as above.)

Fortin's Barometer

This is a barometer which is set up permanently, with a scale fixed to the tube for the purpose of reading the height. Now if the mercury rises in the tube the level must fall in the basin, and, *vice versa*, if it falls in the tube it rises in the

basin, and the height of the barometer is measured from the level in the basin. And, since the scale is fixed, its zero mark (*i.e.* the point from which the scale is measured) must be a fixed point also. So in the Fortin barometer there is a screw under the basin (the bottom of which is made of leather) by which the level of mercury in the basin can be raised or lowered to the zero mark, which is indicated by the apex of a little cone. Before reading, therefore, it has to be adjusted by means of the screw.

The Barograph

This is a self-registering aneroid barometer where, by a suitable arrangement of levers, the height is recorded on a drum carrying a graduated sheet of paper, the drum being rotated by means of clockwork.

Influence of Pressure on the Boiling Point

The plates of steam boilers are made very strong to be able to stand great pressures, so that if the steam is not allowed to escape at atmospheric pressure, the B.P. of the water is considerably raised, sometimes to as high as 155° C. This gives us superheated steam at the same temperature, which, if allowed to escape from the boiler, does so at very high pressure and is therefore capable of doing more work.

The lowering of the B.P. with decrease of pressure has some interesting applications. Water boils sooner at the top of a hill than at the foot if heated by the same flame, the reason being it boils at a lower temperature on account of the decreased pressure. Water boiling at the foot of a mountain is hotter than water boiling at the top.

At Quito, in South America, it is difficult to boil eggs. The city is about 10,000 ft. above sea level, and at that height water boils at 90° C.

Darwin tells in his *Journal of a Voyage round the World* of how, while crossing the Andes, he boiled potatoes for hours without cooking them. The boiling water was not hot enough, the B.P. being lowered by the low pressure of the air on account of the height. For the same reason the climbers of Mount Everest had difficulty in obtaining a hot drink.

The height above sea level may be found by noting the temperature at which water boils. For every 1080 ft. we

ascend the B.P. is lowered about 1° C. Hence if water boils at the top of a mountain at 84° C. its height is approximately 1080×16, *i.e.* 17,280 ft. The *hypsometer* is an instrument for estimating heights in this way.

Questions on Section VII

1. Distinguish between *mass* and *weight*. How are the mass and the weight of a body measured ?

2. Explain what is meant by the saying, " Water tends to find its own level."

3. How would you make a simple barometer ? What would happen if you used a tube (*a*) 3 ft. long ; (*b*) 6 ft. long ; (*c*) 2 ft. long ?

4. If the mercury in a barometer stands at 30 in., what is the pressure inside the tube—(*a*) at the level of the mercury in the basin ; (*b*) at the vacuum ; (*c*) half-way up the mercury column ; (*d*) 4 in. below the level in the basin ? (1 cu. in. of mercury weighs 0·5 lb.)

5. What could you measure with a barometer besides the atmospheric pressure ? And how ?

6. What is a cyclone ? What kind of weather can we expect when the barometer reads about 28 in. ?

7. Describe experiments to show the effect of change of pressure on the boiling point of a liquid.

8. The boiling point of alcohol is 78° C. What does this exactly mean ?

9. When the mercury barometer stands at 76 cm., what is the height of—(*a*) a water barometer, (*b*) a glycerine barometer ? (Density of glycerine = 1·26 gm. per c.c.)

10. Tell why the names of Hooke, Newton, Torricelli, Pascal are famous in science.

SECTION VIII

PRINCIPLE OF ARCHIMEDES

Flotation

We have learned that a body floating in a liquid is displacing its own weight of that liquid. If, then, the same body floats in liquids of different densities it will displace different volumes

of these liquids, the smallest volume of that with the greatest density, and the greatest volume of that of least density. Hence it does not sink so far into the densest as into the others in order to displace the smallest volume ; in other words, it floats higher out of the densest liquid. This would suggest, then, that by finding how far a body such as a rod of wood sank into a liquid we could ascertain its density. This is the method employed in *hydrometers.*

Hydrometers

These are instruments so constructed and graduated that, by simply floating them in liquids, the densities are found, which is a much less tedious method than weighing. The usual form of such hydrometers is a long glass tube with a bulb carrying a dense substance (like mercury or lead pellets) which enables the hydrometer to float upright.

This method is the one often employed by excise officers in testing the purity of alcohol or spirits, by merchants in testing oils, and by some inspectors in the examination of the quality of milk.

At some fishing centres a very rough hydrometer is made use of in the shape of a raw potato. A potato sinks in fresh water, but, by adding salt, a solution (brine) is got which becomes denser and denser as more and more salt is added. A suitable strength of brine is obtained when the potato just floats underneath the surface of the solution, *i.e.* when the upthrust is just equal to the weight of the potato, or when the brine has the same density.

A fresh egg sinks in water, but a bad egg does not. The density of the egg decreases with the age (owing to the formation of gases inside) and, since the volume remains the same, its weight decreases also. Hence, if totally immersed in water, the weight of water displaced may be greater than the weight of the egg, and therefore it rises to the surface and floats. Thus we have a simple means of testing the quality of an egg.

It has sometimes happened that a golf ball, accidentally driven into the sea at the mouth of a fresh-water river, has sunk and, being washed out to sea where the water is denser, has gradually risen to the surface again.

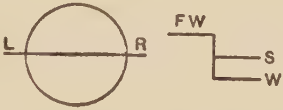
Swimming is easier in the sea than in a river or lake where the water is fresh. Swimming instructors always give the advice to learners to keep the hands well under the water.

Suppose the body all submerged but the head, if the hands or arms be raised out of the water, then there is less water displaced, and so the upthrust becomes less, while the weight of the whole body remains constant. Hence the head must sink to displace the same weight as before.

A boat may be more fully loaded in salt water than in fresh. If it be loaded, say, in a fresh-water port up to a certain mark on its side, this mark will rise out of the water as it goes out into the ocean.

The Plimsoll Line

It will be evident how important it is that ships be not overloaded before setting out on a voyage. Hence the Government cause to be painted on every ship what is known as the Plimsoll Line. This is a horizontal line LR, which must not be submerged when the boat sails in salt water. Another line FW shows the depth to which the boat can be loaded safely in fresh water. Any master who allows his ship to be loaded so as to submerge the Plimsoll Line is liable to prosecution by Act of Parliament. The line gets its name from *Plimsoll*, a Member of Parliament, by whose exertions the law was passed.



Displacement of a Ship

Sometimes in shipping news in the newspapers we observe the statement that a certain ship has a "displacement" of, say, 10,000 tons. This means that it is so built that when it has its crew, passengers, and full load, it will sink into water until it is displacing 10,000 tons. Hence, by the Law of Flotation the weight of the boat and its load together will weigh 10,000 tons.

The Submarine

This is a boat so constructed as to be able to float on the surface of the sea, or sink underneath and so lie concealed from an enemy. It contains tanks into which water may be allowed to enter, and so the boat becomes heavier, with the result that it sinks farther into the water and is finally submerged. To make it rise, the water may be partially or wholly

forced out of the tanks again by means of compressed air, so that the weight of the boat and its contents becomes less than the weight of water it is displacing, *i.e.* less than the upthrust, and it consequently rises.

The Cartesian Diver

The working of the submarine may be illustrated by the toy known as the "Cartesian diver," invented by the Frenchman *Descartes* (1596–1650), hence the name. It consists of a glass figure, with a small bulb on the head containing air, and with a small hole in the lower part by which water may enter. By alternately warming the air and thus expelling some, and cooling under water, we can get sufficient water to enter as to make the diver float with just a small part out of the water in a large bottle. In this position the upthrust equals the weight of the diver. By stretching a piece of rubber over the mouth of the bottle and pressing it gently with the fingers, we compress the air above the water in the bottle. This pressure is communicated to the water, and thence to the air inside the figure, and hence more water enters the diver, thus increasing its weight, and it commences to sink. By manipulating the pressure on the rubber and thus regulating the amount of water entering the diver, we can make it descend, ascend, or remain stationary anywhere in the water.

Why a Balloon Rises

The Principle of Archimedes is a law which applies to all fluids, gases as well as liquids. Thus a balloon in the air is displacing air, and therefore experiences an upthrust equal to the weight of air it displaces. If the balloon is filled with hydrogen say, then, since this gas is very much less dense than air, the weight of the balloon (including, of course, the hydrogen) is less than the weight of air displaced, *i.e.* the weight of a volume of air practically the same as the volume of the hydrogen. Hence the upthrust on the balloon is greater than the weight of the balloon itself, and therefore it rises.

The balloon will stop rising when the upthrust is equal to the weight of the balloon. This would happen when a height was reached where the density of the air had become almost as low as that of hydrogen. Before this height, however, the

hydrogen would probably have diffused sufficiently to make the density of the gas inside more near that of the air outside.

Questions on Section VIII

1. What is the Principle of Archimedes ? Why is it so called ? State the Law of Flotation.
2. Under what conditions do bodies sink or float ? Would an iron 56-lb. weight float in mercury ? Give a fully reasoned answer.
3. A piece of iron whose volume is 20 c.c. is weighed in air and then in water. If its density is 7 gm. per c.c., what is the upthrust in water, and what does it weigh in water ?
4. What is meant by saying that the "displacement" of a certain ship is 20,000 tons ?
5. Explain how you could find the weight of a candle without the balance.
6. A plate, a cup, and a saucer have all the same weight. The plate cannot be made to float in water, but the cup and the saucer can. Explain why.
7. A piece of ice floats in water. Why ? If it is pushed down and then let go it comes up again. Why ?
8. One c.c. lead (density 11·4 gm. per c.c.) and 20 c.c. wood (density 0·5 gm. per c.c.) are tied together and thrown into water. Will they sink or float ?
9. Apply the Principle of Archimedes to explain why a submarine sinks and rises ; and also to explain why an airship rises.
10. A brick suspended from a spring balance is lowered into water in a bucket, which is also suspended from a similar balance. What difference will be observed in the two balances ? Explain.

SECTION IX

MAGNETISM

In the maximum and minimum thermometer—that is, a thermometer which registers the highest and the lowest temperatures reached during a certain period (say, a day)—the indicators, which follow the mercury thread at both ends, are made of steel. These indicators are left when the mercury recedes, so that we are able to read the temperatures—highest

and lowest. A little magnet is used to draw them back to the end of the mercury thread. Its action acts through the glass.

Magnets are sometimes usefully employed in finding sewing needles which have been lost in a rug or in the inside of a pin or needle cushion. Simply draw the magnet through the material and the needles cling.

Care must be taken when a large magnet is brought near a smaller or weaker one, lest the magnetism in the latter be reversed. For example, if the N-pole of the strong magnet be brought close to the N-pole of the weak one it will induce a south pole in the latter, and thus the magnetism will be opposite to what we expect, *i.e.* it is reversed.

When visiting an electric power-station, where very strong magnets are used in the generating dynamos, visitors are requested to leave their watches some distance away, because the iron or steel parts are liable to be magnetised by induction in presence of the " field " magnets as they are called, and thus the watches may be put out of order.

Vertical iron railings and the large girders of iron bridges and buildings are magnetic on account of the inducing effect of the earth's field.

Scientists are frequently engaged in studying the earth's magnetism and carry very delicate magnetic instruments, which would easily be put out of order by induction if near iron or steel. The ships used on such work must therefore be built entirely of wood, or some non-magnetic metal like brass.

Questions on Section IX

1. How would you show that the earth is a magnet ?

2. Explain the meaning of *magnetic induction, susceptibility, retentivity, pole, declination, magnetic meridian.*

3. What is the mariner's compass ? How is it made sensitive ?

4. Describe the method of magnetising a piece of steel (*a*) by single touch, (*b*) by divided touch.

5. If two sewing needles are hung from the end of a magnet by the points, do the other ends come together, or do they go apart, or do the needles remain parallel ? Explain.

6. Why are permanent magnets made of steel and not of iron ?

7. How can small needles be discovered in the sawdust of a pin-cushion or in a rug ?

8. You are given two steel needles, one of which is magnetised. How would you find out by means of a piece of wood floating in water which is magnetised ?

9. A bundle of magnetised sewing needles, each in a small piece of cork and having all the north poles upwards, is placed in a basin of water. What will happen ?

10. How would you magnetise a needle so that the point would be a north pole ?

11. Why does a horse-shoe magnet draw a piece of iron with a greater force than a bar magnet ?

12. A strong magnet brought near the pole of a weak magnet repels it. But if you bring the same two poles much closer they attract. Explain why.

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